PHYSICS AND SOCIETY

Volume 20, Number 1 **January 1991**

Letters
2 Israeli Ballistic Missile Capabilities: *I. Alexeff, S. Fetter*
2 Health Effects of Ionizing Radiation: *B.R. Litt, W.M. Saslow, I.A. Lerch, J.J. O'Grady, R.K. Adair, T.S. Tenforde*

Articles
4 A Lunar-Energy SDI Civilian Conversion Proposal: *L.A.P. Balazs*
6 Symposium on Science and Math Precollege Education:
6 I. Scope, Sequence, and Coordination of Secondary Science: *B.G. Aldridge*
9 II. Precollege Programs of AAPT, AIP, APS: *J.R. Franz*
11 Symposium on Missile Technologies and Nuclear Arms Control:
11 I. Arms Control and Breakout from Treaties: *M.I. Sobel*
13 II. Short Time-of-Flight Nuclear Weapons: *L. Gronlund, D.C. Wright*
16 III. Deterrence Through a Comprehensive Ballistic Missile Flight-Test Ban: *R. Sherman*

Review
16 Reversing the Arms Race: How to Achieve and Verify Deep Reductions, edited by F. von Hippel and R.Z. Sagdeev: *L. Sartori*

News
17 "Thanks" to Bill Havens from the Forum • Kudos for *Physics and Society* • Cincinnati Meeting: Invited Sessions • Washington Meeting: Contribute a Paper! Short Course on Global Warming, Invited Sessions • Call for Ideas for Sessions and Studies! • Does Anybody Have Any Old Newsletters? • To Receive *Physics and Society*!

Comment
19 The Forum Enters Its Third Decade • The Newsletter: Identity Crisis At Twenty? • War And Oil

The American Physical Society
335 East 45th Street
New York, NY 10017-3483

Non-Profit Org.
U.S. Postage
PAID
Rockville Centre
N.Y.
Permit No. 129

MHA0C9215 HEL 05/91 ***** FORUM
DAVID A HAFEMEISTER
3304 MCKINLEY NW
WASHINGTON DC 20015

Physics and Society is the quarterly of the Forum on Physics and Society, a division of the American Physical Society. It presents letters and reviewed articles on the relations of physics and the physics community to government and society. It also carries news of the Forum and provides a medium for Forum members to exchange ideas. Opinions expressed are those of the authors only and do not necessarily reflect the views of the APS or of the Forum. Contributed articles (2000 words maximum, technicalities are encouraged), letters (500 words), comments (1000 words), reviews (1000 words), and brief news articles, are always welcome. They should be sent to the editor: Art Hobson, Physics Department, University of Arkansas, Fayetteville, AR 72701, 501-575-5918, FAX 501-575-4580. Typist: Sandra Johnsen. Layout: Page Perfect, Inc. of Fayetteville.

LETTERS

Israeli Missiles

Steve Fetter's article (October 1990) on Israeli ballistic missile capabilities is way off on the required size of a nuclear bomb. He uses 400 kg as a payload. *US Nuclear Weapons* by Chuck Hansen (Orion Books, 1982), p. 176, discusses a nuclear 155 mm shell weighing 43 kg. This is a "neutron bomb," code W-82/XM-785. Putting this into the Israeli rocket makes it an ICBM.

Igor Alexeff
Professor
Electrical and Computer Engineering
University of Tennessee

Response:

Igor Alexeff is correct that the US has developed nuclear weapons weighing as little as 43 kg (even lighter—the W54 Special Atomic Demolition Munition weighs only 27 kg), but such light designs were only developed after hundreds of nuclear tests and tens of billions of dollars. Moreover, these devices are not complete warheads; the lightest US *warhead* (the W68 Poseidon) weighs about 75 kg. One must also include the mass of an inertial guidance system, so the minimum payload mass would be 100 kg—achievable only after a substantial nuclear testing program.

Unless one counts the 1979 "flash in the South Atlantic," Israel has not tested. As I stated in the article, Swedish scientists had a 1958 developed a 20-kt bomb (not a warhead), *in which they had high confidence without nuclear testing*, but it weighed 600 kg. Although Israel may now be more advanced in nuclear design than Sweden was in 1958, theory is never a complete substitute for experiment. I think that 400 kg is a realistic minimum for an untested, first-generation warhead and inertial guidance system.

In any case, Fig. 1 gives a payload mass of 460 ± 50 kg at intercontinental (10,000 km) range. Thus, choosing a payload mass less than 400 kg does not change the conclusion that Israel may possess an ICBM capability.

Steve Fetter

Health Effects of Nonionizing Radiation

Reading Robert K. Adair's article (October 1990), I was astonished by the vilification of researchers who choose to work in this field ("Good men do not consider time spent correcting the work of their inferiors well spent..."). I hope that this statement does not typify physicists' concern for society. While it is certainly important to discuss the question posed by the title, the material presented by Adair has been treated more thoroughly by Weaver and Astumian in a peer reviewed journal article (1). In their paper, the authors point out that, were a cellular mechanism of signal averaging to exists, the field strengths at which "effects" have been seen could be reconciled with theory. Adair was either unaware of this, or chose to ignore it.

Barbara R. Litt
Research Scientists
New Jersey Department of Environmental Protection (2)

1. J.C. Weaver and R.D. Astumian, "The Response of Living Cells to Very Weak Electric Fields: The Thermal Noise Limit," *Science*, Vol. 247, 26 January 1990, 459-462.
2. Affiliation given for identification only. The views expressed here are my own, and do not represent official policy.

I took much interest in the three articles. Having read the original *New Yorker* articles, I was aware of the scanty evidence for (but possibly important implications of) low-frequency fields, and I was hoping to learn more.

Instead, I found three inadequate articles. Tenforde's Figures 3 and 4 are the only attempts to show data, and that was extremely sparse. Morgan's article rushes forward to consequences without discussing its basis in adequate detail. Adair presents reasonable theoretical arguments, but presents no information or references supporting his claim that "Attempts to replicate the more loudly advertised results have failed." Unless there is published data and descriptions of experimental procedure, there will be constant claim and counterclaim. If the effect is not real, there will be constant repetition of experiments yielding a null result, and general uncertainty among scientists as to what is true.

I would urge scientists who obtain null results in experiments relating to controversial areas to try to publish their results in refereed journals. Yes, it would seem to be a thankless task. Nevertheless, it would have long-term impact on the scientific community. In the case of cold fusion, ad hoc Conference led to ad hoc Conference Proceedings, but very little that was accessible to the scientific public through conventional sources. I would hope that ELF gets scrutinized in a conventional fashion.

Wayne M. Saslow
Professor of Physics
Texas A&M University
College Station, Texas 77843-4242

The three articles are disturbing, not because of the controversy but because of the narrowness with which each author addresses the subject.

I cannot accept Professor Morgan's assertion that there has been a Kuhn-type "paradigm shift" which has begun to nurture scientific acceptance of the hazards of ELF fields. I will illustrate my objection by contrasting our understanding of ELF effects with the history of ionizing radiation safety concepts.

Within months of Röntgen's discovery of x-rays, the literature began carrying reports of radiation injury, usually in the form of erythemia, epilation, and moist desquamation. The general attitude was that these injuries were inconsequential since they mimicked the effects of protracted exposure to the sun and that x-rays were therefore much the same as sunlight. The severity of these injuries prompted some physicians to attempt to use the new radiation therapeutically in the treatment of skin disease, notably lupus and some superficial cancers. And since it was long known that sunlight has a bactericidal effect, many physicians hoped that ex-rays would prove useful in the treatment of infectious diseases.

However the first crude radiobiological experiments failed to demonstrate any significant impact of x-rays on bacterial growth or survival. Thus the propensity to dismiss observed radiation injuries as unimportant was reinforced since the prevailing attitudes held that if the radiation was incapable of damaging lowly organisms such as bacilli, they could hardly pose a hazard to higher organism such as humans. It was an attitude that would prevail well into the next century despite the discovery by 1906 that chronic radiation exposure was associated with skin cancer.

It was not until 1927, when Muller published his startling findings (eventually recognized with the Nobel Prize) in *Science* linking the mutagenic and oncogenic effects of x-rays in fruit flies, that a sound biological basis was finally formed to support studies in radiation safety. Ultimately, the link to human populations would be made in epidemiological studies of radiation workers, uranium miners, and radium-dial painters. And in the cataclysmic aftermath of Hiroshima and Nagasaki, the work would be forever tainted with the colors of the apocalypse.

Physicists were equally hampered at the turn of the century. Aside from Röntgen's careful characterization of the properties of x-rays, Lenard's study of cathode rays, and the work of Becquerel and the Curies on radionuclides, nothing was known about the nature of radiation, the structure of matter, or the mechanisms of energy transfer from the radiation field to an absorbing medium. The amount of energy transferred was known to be small, of course, but in the absence of any knowledge concerning the nature of chemical bonds and the atomic and molecular interactions attending radiation diffusion, few could even speculate as to the possible links between an exposure and a biological end-point.

The association between the stochastic microdosimetric properties of radiation and radiobiological effects was not tackled until the postwar era. It was hoped that this research would help resolve the growing dispute in radiation protection concerning low-dose effects. There is still a significant gap in our knowledge about relative biological effects and the microdosimetry of mixed radiation fields.

The paradigm shifts associated with our growing awareness of ionizing radiation risks required fundamental discoveries in physics, chemistry, biology, biochemistry, molecular biology, and clinical medicine. The process, which began in 1896, did not achieve maturity until the 1930s, even though acute radiation effects were widely reported almost immediately. By then, the efforts of a few professional radiation workers finally succeeded in generating a consensus among international and national bodies which forced the acceptance of radiation standards.

Today the ELF situation is much different. Large industrial populations have been exposed to strong ELF sources for almost three generations. Few acute effects have been reported. The immediate concern has been generated by a small number of contradictory epidemiological studies which , by their natures, cannot be construed as definitive. A great deal of physics and chemistry is available to the serious researcher to assess models of interaction to account for any biological effects discovered in the laboratory. The real relevance of the cellular studies summarized by Dr. Tenforde is unclear. What we appear to be seeing, on the epidemiological scale, is a threshold effect which may not be easily characterized in a dose-response relationship.

If there is to be a paradigm shift then a broad investigation is required in physics, dosimetry, microdosimetry, cellular biology, animal studies, and epidemiology. This obliges all participants to address the issues raised by Professor Adair. The problem here is that most physicists who have worked in medicine are familiar with the many blind alleys and false trails which have appeared to link physical phenomena with biological manifestations, often in the guise of a potential cancer cure. The work is usually reasonably carefully done but imprudently interpreted since the workers were either ignorant of the elementary physics or overlooked it. It is important that the physical and biological variables be carefully controlled in any experiment which purports to discover a relationship between an environmental factor and some biological consequence. The main difference between most physics and biological laboratory work is that biologists face the more difficult task of controlling a broad collection of potential covariates.

We have a long way to go and I would prefer to see multidisciplinary forums in which the science is the focus of the debate and not the personalities of the participants.

Irving A. Lerch, Ph.D.
Professor of Radiology
New York University Medical Center
566 First Avenue
New York, NY 10016

In the second sentence of the introductory paragraph of Tenforde's article (October 1990), values of wavelength and skin depth are stated. My calculations for the skin depth and wavelength due to a 60 Hz field in a nonmagnetic ohmic conductor are that of 150 m skin depth corresponds to a wavelength of 666 m, not the 5000 m stated; a wavelength of 5000 m corresponds to a skin depth of 1125 m, but then the electrical conductivity is .00333, less than the minimum 0.01 stated in Figure 1 of the article. Can you account for the discrepancies?

Further on in the introductory paragraph, the author alludes to "uncoupling" and the "quasi-static approximation." Since in a time-varying field the electric field and the magnetic induction field are coupled regardless of frequency, it is not clear to what the author refers. Is he alluding to the fact that the displacement current in a "good" conductor is negligible relative to the conduction current, so that the resulting quasi-stationary field is the solution of the diffusion rather than the wave equation? Note also in this regard that the electric field in the conductor is not divergenceless unless the conductor is homogeneous, so that a volume distribution of electric charge may exist in an inhomogeneous conductor.

More fundamentally, the usefulness of modeling the human body as a classical electrical conductor is not clear. It is apparent that the body comprises many material regions which are electromagnetically discontinuous at material interfaces. Also even within a continuous region the assumptions of homogeneity and isotropy may not be warranted. Are there experimental data which support the assumptions of the model?

John J. O'Grady
1305 N. Harlem Avenue
Oak Park, IL 60302

Response from Adair:

Ms. Litt states that my remark that "Good men do not consider time spent correcting the work of their inferiors well spent..." is a "vilification of researchers who choose to work in this field." Many of the most eminent of those researchers (among whom I number my wife, Eleanor R. Adair) have strongly encouraged me in my presentation of the views that exercise Ms. Litt.

She then infers that my note indicates a lack of "concern for society." Uncritical acceptance of bad science hardly equates to a concern for society.

Ms. Litt then complains that I ignore the interesting *Science* paper by Dean Astumian and Jim Weaver, assuming, incorrectly, that my note is in substantial disagreement with their hypotheses. Weaver and Astumian discuss explanations of biological effects on large cells that seem to be induced by *internal* fields (in the tissue) of about 0.005 V/m. External fields (in the air about the tissues) of 50 kV/m or more, very much larger than those I hold harmless, would be required to induce such fields at the cells. Ms. Litt has mislaid a factor of about 10,000,000.

My *Physical Review A* paper on the subjects I addressed in the *Physics and Society* note, which should appear soon, was written after I was encouraged to do so by Astumian and Weaver, and by others.

Prof. Saslow says that the articles (including mine) are inadequate. I was requested to limit my note to 2500 words which limit is inadequate for some purposes. My more complete *Physical Review A* paper is in press.

I note here, that the results presented by Tenforde (his Figures 3 and 4) concern fields higher by orders of magnitude than the week fields in our environment or the fields that I discuss. I do not argue that the results Tenforde describes are impossible.

Dr. Lerch says that my note (as well as the others) was "narrow." I agree. But I hold that the area I addressed, the physical limitations of the interactions of weak fields, is fundamental.

I agree with Dr. Lerch that there has been no Kuhn "paradigm shift" in this field. I gather Prof. Morgan—who holds that there is—considers that a proof of the biological effects of very weak electromagnetic fields would be as revolutionary as the Copernican solar system, the Theories of Relativity, and Quantum Mechanics. I concur.

Robert K. Adair

Response from Tenforde:

Regarding O'Grady's comments, the skin depth of approximately 150 m for a 60-Hz field in tissue was calculated with the reasonable assumptions that the body is nonmagnetic and the average conductivity of soft tissue is about 0.15 S/m. In general agreement with O'Grady's value, I calculate the wavelength of a 60-Hz field in the body to be slightly less than 1000 m (the 5000 m stated in my paper was a typographical error on my part).

For ELF fields O'Grady is also correct in stating that the displacement current is negligible in comparison with the conduction current in tissue. Treating the electric and magnetic components of ELF fields as uncoupled in their interaction with body tissues is a reasonable approximation.

The third point made by O'Grady is also correct, since the changes in electrical conductivity at interfaces between bone and soft tissues must be taken into account in modeling induced currents. The electrical anisotropy of muscle tissue should also be taken into account in detailed models. The intent of my brief discussion of currents induced in the body by ELF electric and magnetic fields was simply to point out their macroscopic characteristics. The general features of the induced current profiles that I described have been demonstrated in laboratory measurements with saline-filled human "phantoms" and with animal carcasses.

T.S. Tenforde

ARTICLES

A Lunar Energy SDI Civilian Conversion Proposal

Louis A.P. Balázs

The winding down of the Cold War has stimulated a lively debate on the conversion of defense programs into civilian projects. Such a redirection is difficult, and is likely to be resisted, unless civilian projects can be found which would use similar specialized experience and capability (1).

We discuss a prototype proposal for a space propulsion and power technique with an effective efficiency highly amplified by the large gravitational potential difference between the surfaces of the moon and Earth, and using technology developed by the Strategic Defense Initiative (SDI) and other Department of Defense programs. Even if this particular scheme should encounter insurmountable problems, it might hopefully at least serve as a model for other "Swords into Plowshares" proposals.

Impact propulsion

Once even a modest lunar base is established, e.g. as part of President Bush's Moon-Mars Initiative, it will be possible to launch appropriately fabricated packets of lunar material from the moon towards Earth with relatively little energy, using e.g. nuclear- or solar-powered electromagnetic or rotary-pellet launchers (2), or even chemical rockets using lunar oxygen. with the help of the NAVSTAR satellite global-positioning system (3), which can pin down positions to within a few meters near Earth, together with SDI-type sensor, guidance and steering technology (4), the gravitationally-accelerated stretched-out low-density packets could be made to home in on and impact "pusher plates" on initially-slow vehicles lifted, e.g., by simple air-breathing ram jets, to points I just above the atmosphere (Fig. 1); velocities no higher than 1.4 km/sec would be needed to reach 100 km. The impacts would then accelerate the vehicles into Earth orbit, deep space, or even sub-orbit (for rapid inter-continental transportation).

The actual guidance and steering of the lunar "impact packets" and impacted vehicles could be performed by sensor-thrusters similar to SDI "smart-rocks" or "brilliant pebbles" (5). These would separate themselves from the impact packets at the last moment to just barely avoid impact themselves, and proceed to

Louis A.P. Balázs is with the Department of Physics, Purdue University, West Lafayette, IN 47907. *The author thanks Professor S. Van Wyk for a helpful correspondence.*

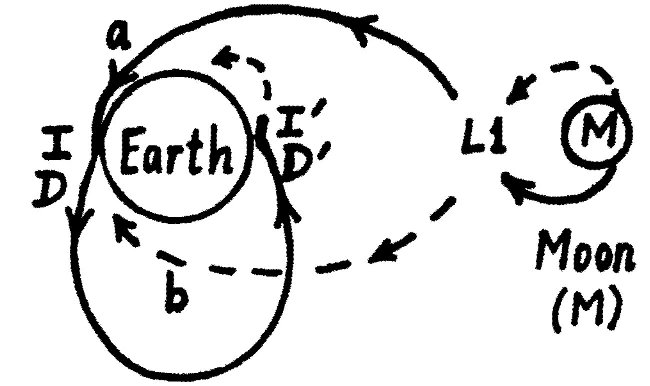

Figure 1. Schematic approximately elliptic impact packet trajectories (a,b) from the moon for low-altitude direct impact (I) or impact elsewhere (I') after aerodynamic upper atmosphere deflection (D,D').

appropriate points between the Earth and the moon to be reattached, at low relative velocity, to fresh lunar impact packets for reuse (6). Alternatively, external lasers on Earth, in orbit or on the impacted vehicles themselves could steer the impact packets with small controlled surface-ablation thrust-producing "ping" pulses. This should be possible with existing laser power levels (4).

Impact

For extended material of length x_o, velocity v and mass m impacting the pusher plate on a vehicle of velocity V and mass M, energy-momentum conservation gives a velocity increment in the v-direction of $dV = \alpha(v - V)dm/M$ for every successive portion dm of m; $(\alpha - 1)$ is an elasticity coefficient, with $\alpha = 2$ corresponding to an elastic collision and $\alpha = 1$ to a dm-velocity equal to V after its collision with M. We assume that dm is immediately dispersed after impact, and that the exposed surface of the plate is covered with an ablating or other substance protecting the underlying structure, a negligible part of the substance being removed by the impact (7). With constant v and α, and $1 < \alpha < 2$, the final M-velocity after an m-impact is then

$$V = v[1 - \exp(-\alpha m/M)(1 - V_i/v)] \qquad (1)$$

for an initial velocity V_i and the impact efficiency is

$$\varepsilon_I \equiv M(V^2 - V_i^2)/mv^2 = a(V^2 - V_i^2)/v^2 \ln[(v - V_i)/(v - V)] \qquad (2)$$

With constant average M-acceleration a and $V_i = 0$,

$$(aM/\alpha v^2)(dx/dm) = \exp(-2\alpha m'/M) = 1 - 2ax/v^2 \qquad (3)$$

for a mass portion m' within a distance x from the end where our m-material first begins to impact the pusher plate. Attaining a low-Earth orbit (LEO) $V^2 = Rg$ with $R \approx R_e$ = radius of Earth, would require a total $x = x_o = 5700\ g/a$ km, if $v = 1.40V$, which maximizes ε_I.

Lunar impact material

Although terrestrial material accelerated from Earth and/or space can be used for our impact packets, lunar material launched from the moon (with efficiency ε_m) requires a much lower launch velocity v_m to attain the same v (6). Assuming an Earth-moon distance >> R, R_m, energy-conservation gives

$$v^2 - v_m^2 \approx 2G(M_e/R - M_M/R_M) \int V_t^2, \qquad (4)$$

where M_e and M_M are the masses of Earth and moon, and R_M is the radius of the moon. With constant v_M, the overall "efficiency" is then

$$\varepsilon \equiv \varepsilon_M M(V^2 - V_i^2)/mv_M^2 = \varepsilon_M \varepsilon_I v^2/v_M^2 \qquad (5)$$

For $V < \hat{V}_t$, ε is maximized with $\hat{V}_t^2 = V_t^2 + m_{Mo}^4/8Rg$ at

$$v_M = \text{lunar escape velocity } v_{MO} = \sqrt{(2M_M G/R_M)} \qquad (6)$$

To attain a LEO $V^2 = Rg = M_eG/R$ we therefore need $v = V\sqrt{2}$, remarkably close to the ε_I-optimal $v = 1.40V$ for $V_i = 0$. Eq.(5) then gives $\varepsilon = 9.0\alpha\varepsilon_M$, with e.g. $\varepsilon_M = 0.30$. This should be compared with the idealized-rocket efficiency

$$\varepsilon' \equiv \varepsilon_R MV^2/m_{fuel}u^2 = \varepsilon_R V^2/u^2(\exp(V/u) - 1) \qquad (7)$$

which neglects the mass of the engines and fuel tanks. With burn efficiency $\varepsilon_R = 0.4$ and chemical fuel exhaust velocity u = 3 km/sec, $\varepsilon' = 0.54\varepsilon_R << \varepsilon$.

For $V > \hat{V}_t$, maximum efficiency requires a variable v_M. With $V_i \rightarrow V$, $V \rightarrow V + dV$ and $m \rightarrow dm$ in Eqs.(2), (4) and (5), $\partial\varepsilon/\partial v_M = 0$ gives $v = V + \sqrt{(V^2 - V_t^2)}$. The overall "efficiency" for $V_i = 0$ is then

$$\tilde{\varepsilon} \equiv \varepsilon_M MV^2/[mv_{Mo}^2 + \int_{V=\hat{V}_t}^{V} dmv_M^2] \qquad (8)$$

with m given by Eq. (1) with $V = \hat{V}_t$, $V_i = 0$ and v from Eqs. (4) and (6); dm by Eq. (1) with $V_i \rightarrow V$, $V \rightarrow V = dV$ and $m \rightarrow dm$; and v_m^2 by Eq. (4) with $v = V + \sqrt{(V^2 - V_t^2)}$. For the Earth escape velocity $V = \sqrt{(2R_e g)}$, for example $\tilde{\varepsilon} = 4.5\alpha\varepsilon_M$, whereas $\varepsilon' = 0.34\varepsilon_R$ for u = 3 km/sec. For a solar elliptic M-orbit tangent to the orbits of Earth and Mars, V = 11.6 km/sec and $\tilde{\varepsilon} = 3.45\alpha\varepsilon_M$, whereas $\varepsilon' = 0.32\varepsilon_R$, an order of magnitude lower.

For the actual finite Earth-moon distance, ε for a LEO-V drops by 12.5% for Eq. (5). Raising v_M decreases ε. An equatorial Earth-rotation $V_i = 0.46$ km/sec raises ε by 3.3%.

Multiple Impacts

Multiple impacts become mandatory for $a \cong g$, since x_o becomes too large. Eqs. (1) - (6) apply on average to the entire impact-packet set, with shock absorbers to transfer the impulsively accelerated pusher plate to a smoothly accelerated vehicle, as in Orion-Project nuclear-bomb propulsion (7). If fM is the mass of the pusher plate (which could include the more rugged part of the payload), sM the mass of the shock absorbers and w the vehicle-velocity increment from each impact, we must have the internal energy of the relative motion of pusher and vehicle

$$-(1 - 1/f)Mw^2/2 < (sM)Y/2\rho \qquad (9)$$

where Y is the tensile strength and ρ the mass density (7). With a typical $Y/\rho = 10^5 m^2/sec^2$, $f = 1/3$ and $s = 1/50$, Eq. (9) gives a maximum $w \cong 30$ m/sec. With $a = 2g$, the interval between impacts is then $w/a = 1.5$ sec and the shock absorber stroke length is $w^2/4af = 34m$. To attain a LEO-velocity V, $V/w(\cong 263)$ impacts would be needed, with a packet spread of $x_o = 2900$ km from Eq. (3), and an impact altitude spread of about 300 km from Fig. 1.

Impact power

Impacting a vehicle from opposite directions can be used to generate power, e.g. from the impact-generated heat, with efficiency e_H. With lunar packets (Fig. 1), the overall "efficiency" is

$$\varepsilon_p \equiv \varepsilon_H \varepsilon_M mv^2/mv^2_m = \varepsilon_H \varepsilon_M M_e R_M/M_M R \qquad (10)$$

if we use Eqs. (5) and (6). With $\varepsilon_M = 0.30$ and $R \cong R_e$, $\varepsilon_p = 6.6\varepsilon_H >> \varepsilon_H$ ($\cong$ typical direct heat-engine efficiency). The impacts could also serve to "levitate" our vehicle and e.g. keep it at a minimum-altitude maximum-ε_p point I (Fig. 1) or geo-stationary point I' or I. Most of our power could be beamed by highly-efficient cloud-penetrating microwave to receiving antennas on Earth (8), perhaps via high-orbit relays. A fraction $F = 1/\varepsilon_p \varepsilon_G$ could also be beamed to a lunar-aluminum received on the moon to provide the power needed to launch our impact packets in the first place; ε_G is the beam generation, transmission and receiving efficiency. A 2.4 GHz beam would require typical optimal transmitting and receiving antenna diameters of 3.1 km and 31 km respectively; a typical heat-engine $\varepsilon_H = 0.35$ and non-heat engine $\varepsilon_M = \varepsilon_G = 0.70$ would give $F \cong 1/3.8$ from Eq. (10) with $R \cong R_e$. All of our power would then come from the moon.

References

1. I. Crawford, *New Scientist* 19 May 1990, pp. 67-68.
2. G.K. O'Neill, *Physics Today* September 1974, pp. 32-40.
3. J. Bell, *New Scientist* 11 October 1984, pp. 36-40.
4. M. Bloembergen et al., *Rev. Mod. Phys.* Vol. 59, No. 3, part II, July 1987. J.A. Adam et al., *IEEE Spectrum* September 1985, pp. 34-64.
5. G. Canavan and E. Teller, *Nature* 19 April 1990, pp. 699-704.
6. L.A.P. Balázs, *Nature* 26 April 1990, p. 807; *Physics and Society* July 1990, p. 2.
7. F.J. Dyson, *Physics Today* October 1968, pp. 41-45.
8. P.E. Glaser, *Physics Today* February 1977, pp. 30-38.

Symposium: Science and Mathematics Precollege Education: What Can We Do?

The Forum, along with the APS Committee on Education, jointly sponsored this invited session at the April 1990 APS meeting in Washington, DC. The session was a cooperative effort of many educational organizations in and beyond physics: American Association of Physics Teachers, National Science Teachers Association, American Association for the Advancement of Science, and the APS Committee on Education. It was designed to encourage further cooperation between these groups.

The lively audience discussion at this session was heavy with criticism of physics and academia. Typical opinions: The physics profession is too research-oriented, and pays scant attention to educational matters. This goes also for the large PhD-producing universities. There are too few rewards for good teaching, and in fact universities and departments actually penalize those who take an active interest in teaching because time devoted to teaching detracts from research and the rewards, especially tenure, stem from research. The publish-or-perish doctrine was criticized. Amid all this criticism, one member of the audience mentioned one praiseworthy educational program: *chemistry* at Berkeley. Apparently, it was impossible to think of a praiseworthy physics program.

Of the four papers presented at that session, I have received only the two manuscripts published here. The other two papers, for which I was unfortunately unable to obtain manuscripts, were "Science Education: A High School Teacher's View," by Clara Tolbert, Central High School, Philadelphia, PA, and "Project 2061," by F. James Rutherford, Director of Project 2061, American Association for the Advancement of Science. *—Editor*

Scope, Sequence, and Coordination of Secondary Science: A Rationale

Bill G. Aldridge

The project

The Project on Scope, Sequence, and Coordination of Secondary School Science (SS&C), initiated by the National Science Teachers Association, is a major reform effort to restructure science teaching at the secondary level. NSTA's plan calls for the elimination of the tracking of students, recommends that all students study science every year for six years, and advocates the study of science as carefully sequenced, well-coordinated instruction in physics, chemistry, biology, and earth/space science. As opposed to the traditional "layer cake" curriculum in which science is taught in year-long discrete and compressed disciplines, the NSTA project provides for spacing the study of each of the sciences spread out over several years. Research on the "spacing effect" indicates that students can learn and retain new material better if they study in spaced intervals rather than all at once, and this way they revisit a concept or idea at successively higher levels of abstraction.

The author is Executive Director of the National Science Teachers Association, 1742 Connecticut Avenue, NW, Washington, DC 20009

The American Association for the Advancement of Science (AAAS) has also embarked on a comprehensive program of reform known as Project 2061. During the first three phases of the AAAS project, leading scientists and educators identified knowledge and skills deemed essential for improved science education. These outcomes have been adopted by NSTA as goals for Scope, Sequence and Coordination.

While Project 2061 and SS&C are quite different in their approaches and their time frames for implementation, both reform efforts share the same goals. Both projects contend that less content taught more effectively over successive years will result in greater scientific literacy of the general public. The SS&C project goes beyond this claim with the considered judgement that less content taught effectively over several years will, from the same pool of young people, produce more and better scientists and engineers.

The fundamental goal of the SS&C project is to make science understandable by essentially all students. As so well expressed in the "California Framework:"

"The structure of the natural world requires language to explain it. But there are many ways to describe natural phenomena. Customarily, we recognize a phenomenon and give it a name...Sometimes in science curricula, remembering the names and their definitions seems to become an end in itself. But a name should not become more important than the phenomenon being described, or than its empirical or logical relationships with other phenomena."

In order to concentrate on experience with phenomena, the number of topics included in the restructured scope and sequence and their accompanying baggage of facts and terminology is greatly reduced. This leads naturally to less continuity than when one must "cover" everything. However, fewer topics will result in more in-depth student learning and far greater student retention.

The SS&C reform effort emphasizes appropriate "sequencing" of instruction, taking into account how students learn. In science, profound understanding comes from having concrete experiences with a phenomenon before it is given a name or a symbol. These experiences must also be in several different contexts before the concept becomes part of one's mental repertoire. With such prior hands-on experience, students can understand science. The practical applications of science should begin in the seventh grade with issues and phenomena of concern to students at a personal level and then move toward more global applications in the upper grades. As students mature, they are able to generalize from concrete, direct experiences to form abstractions and theories. With a sequenced approach students will no longer be expected to mindlessly memorize facts and information. With personal and societal applications, science will make sense and have relevance to their lives.

As opposed to the "layer cake" curriculum,—the project provides for spacing the study of each science over several years

Another SS&C component is "coordination." Earth/space science, biology, chemistry, and physics have topical areas and processes in common. Coordination among these four subjects leads to awareness of the interdependence of the sciences and how they fit together as part of a larger body of knowledge. Project 2061 also emphasizes the importance of coordinating themes. NSTA has adopted themes identified by 2061 as the unifying threads of science and related applications.

Table 1 illustrates one possible configuration of four science subjects taught over a six-year period. Notice that at first students experience most intensively the descriptive and phenomenological aspects of the sciences. The abstract and theoretical emphasis occurs in later years. Empirical and semi-quantitative treatments are emphasized in the middle years. Computers, technology, and practical applications should be integrated directly into each of these subjects.

Table 2 illustrates how the model has been adapted for use in the California Framework.

Table 1. Example of a revised science curriculum for grades 7 through 12 in the United States

Grade level	7	8	9	10	11	12	Total time spent
			Hours/week by subject				
Biology	1	2	2	3	1	1	360
Chemistry	1	1	2	2	3	2	396
Physics	2	2	1	1	2	3	396
Earth/space	3	2	2	1	1	1	360
Total hrs/wk	7	7	7	7	7	7	
Emphasis	descriptive, phenomenological		empirical, semi-quantitative		theoretical, abstract		

Table 2. Example of a revised science curriculum for grades 7 through 12 in California

Grade level	7	8	9	10	11	12	Total time spent
			Hours/week by subject				
Biology	2	2	1	1	1	1	288
Chemistry	1	1	2	2	1	1	288
Physics	1	1	1	1	2	2	288
Earth/space	1	1	1	1	1	1	216
Total hrs/wk	5	5	5	5	5	5	
Emphasis	descriptive, phenomenological		empirical, semi-quantitative		theoretical, abstract		

Why reform is needed

The time is right to embark on a reform effort in science education. As numerous reports and studies indicate, schools in the United States are failing to educate students for a world that depends more and more on sophisticated and rapidly changing science and technology. Surveys show that the majority of students leave our schools without a basic understanding of science, mathematics, or technology. Neither the demand for scientists and engineers is being met, nor are schools preparing future citizens with an adequate background of knowledge necessary to make decisions affecting their lives.

Students perceive currently structured, textbook-drive science subjects as difficult, boring, and having no relevance to their lives. Many opt out as soon as the system allows—over half our students don't take another science course after 10th grade. Only 19% of high school students take a course in physics and only about 40% take a course in chemistry.

There is an incorrect assumption widely held that only certain children are capable of learning science and mathematics. Students, identified at an early age as "most able" or "most intelligent" are tracked into future course work in science and math. These are often the most advantaged. The remainder are systematically filtered out of science and math. The research-based underlying principles of the SS&C initiative are that science is needed by everyone and that everyone is capable of learning and enjoying science. Students stay in science until they have had several years of a good learning experience in each of the coordinated science subjects.

With personal and societal applications, science will make sense and have relevance to their lives.

The emphasis of SS&C is on science for *all* students. Truly gifted students will not be overlooked. They are likely to be a different mix of gender and ethnicity, and they will be rewarded for *quality* of learning and thinking rather than for rushing through and completing the course work ahead of their peers. Such gifted students, as well as other more enthusiastic and interested students, will be provided enrichment activities to maintain their interest. They can also be given additional responsibilities in cooperative learning situations, e.g., students teaching students.

Conditions for reform

To be successful, a major reform effort requires change and accommodation on the part of science teachers and school administrators. Challenges relating to scheduling, teacher training, parental support, and assessment must be addressed. The SS&C Project recommends at least five class periods a week of science in each of six years. Adding more time to science requires creative scheduling decisions. Whatever the administrative decision regarding scheduling, there will be difficult problems of balance. But, educational reform cannot take place without making some decisions which, at first, may not be popular.

Inservice teacher training must occur concurrently with curricular change. For seventh-grade teachers, the SS&C plan will mean focusing on four science subjects rather than on traditional middle school life science or earth science courses. This may require additional knowledge in those subject areas in which teachers currently may have only limited preparation. Interaction with colleagues who teach other science subject is important in maintaining a properly sequenced and coordinated science program. NSTA recommends that teachers at the middle/junior high level teach no more than two science subjects. Even with two fields, most teachers will need to be updated in at least one subject area. Summer inservice and monthly one-day weekend education in each of the four discipline areas should be provided to address teacher needs. Teachers may have more classes of students, but if they teach the same students for at least two years, they will know their students better and will be able to keep track of their progress over a longer period of time.

Since specific science subjects will be taught only a few periods a week rather than everyday, homework and out of school explorations will be an essential extension of the classroom. Homework exercises will help maintain continuity in student learning. To insure community support, school personnel should meet with parents of all students in project classes to explain the goals of the reform effort and how it will benefit their children. Parents should be made aware of the different expectations for out-of-class work and their role in helping students meet these expectations.

SS&C priorities suggest a vital shift of focus. The focus of science must move away from the textbook, tests, and even the teacher. It must move to the student. The textbook, the test, and the teacher are there to serve the student, not to control, dominate or make the student feel inadequate in the face of a massive unknowable mountain of information. Rather, the teacher is there to provide the circumstances in which learning can take place.

If the focus of the learning process is the student, what doe does this imply in practice? It implies that students will learn most readily when they are given the opportunity to challenge and develop their own theories, to collect their own data, to present their own outcomes of their investigations; in other words, to take responsibility for their own learning.

Students will learn most readily when they — take responsibility for their own learning.

Within the existing models of science teaching, many teachers rightly complain that there is far too much to cover in textbooks. Some teachers respond by not using tests; and while many teachers are able to work without such a supportive framework, many more feel inadequate to teach without one. There is a direct parallel between students taking responsibility for learning, and teachers taking responsibility for teaching. No longer is the teacher obliged to be a holder of knowledge (encyclopedias can do that) but rather a teacher should be a manager of the learning environment—someone whose role is to liberate the potential of the students. The teacher's role is to create a physical and intellectual environment in which students are enabled to learn for themselves.

Development of SS&C

To assist school districts implementing SS&C programs, NSTA appointed four curriculum committees to identify science topics to be taught in each discipline at each grade level. Committee members were experts in the discipline areas and consisted of university professors, classroom teachers, curriculum developers, and textbook authors. Prior to determining the scope of science topics, they examined an umber of sources, including the goals identified by Project 2061, the themes presented in the California Framework, the major textbook series, science trade books, and a number of curriculum projects, After an initial list of topics was formulated for all secondary grade levels, the committees concentrated on the seventh grade, since the first trials of the reform are to be implemented at this level. In selecting the topics to be taught in a restructured seventh-grade science curriculum, committee members worked with the precepts inherent to the project.

- The four basic subject areas, earth/space science, biology, chemistry, and physics, are addressed each year, and the connections among them are emphasized.
- The coordinating themes identified by Project 2061 are used as unifying threads among the science disciplines. These themes are systems, models, constancy, patterns of change, evolution, and scale.
- Science is shown to be open to inquiry and skepticism, and free of dogmatism or unsupported assertion by those in authority. The curriculum promotes student understanding of how we come to know, why we believe, and how we test and revise our thinking.
- Science is presented in connection with its applications to technology and its personal and societal implications.
- Science relates to the student's own experiences and interests and frequently involves hands-on experiences.
- Students have the opportunity to construct the important ideas of science which are then developed in depth through inquiry and investigation.
- Vocabulary is used to facilitate understanding rather than as an end in itself. Terms are introduced only after students experience the phenomena.
- Texts are not the source of the curriculum but serve as references. Everyday materials, laboratory equipment, video, software, and other printed materials such as reference books and outside reading provide a substantial part of the student learning experience.
- Lessons provide opportunities for skill building in data collection, graphing, record keeping, and the use of language in verbal and written assignments.
- Enhancement activities or "extras for experts" are provided for the more enthusiastic and interested students.
- Of particular importance is that instruction enhances skepticism, critical thinking, and logical reasoning skills. During instruction teachers need to ask, "How do you know?" "Why do you believe?" and "What is the evidence?" Thinking and reasoning skills to be fostered include students ability to:
  - control variables to determine relationships.
  - understand the meaning and use of ratio, proportion, and scaling laws.
  - draw inferences from evidence and discriminate explicitly between evidence (or the observations) on one hand and the inference being drawn on the other.
  - recognize gaps in available information or knowledge when such gaps exist.
  - define technical terms operationally after the idea behind the term has been developed.

The selection of topics and activities for seventh-grade science will be based on relevance of the instruction to the students themselves, their lives, their future, and their immediate environment. Applications will relate to the students' personal lives first. These will be broadened to include application at the level of family, community, and global concerns over the six years of study. There will be a minimum of symbolic or mathematical abstractions in seventh grade science. Students will be presented with experience first, then terms and then reinforcement with applications. The emphasis at first will be on concrete rather than abstract ideas and on lessons that involve hands-on activities and experience with natural phenomena.

Acknowledgments

NSTA acknowledges the invaluable assistance of all members of the curriculum committees working on Scope, Sequence, and Coordination. In particular, NSTA recognizes the extra efforts of committee members James Robinson, Arnold Arons, and Floyd Mattheis.

The Pre-College Programs of AAPT, AIP, and APS

Judy R. Franz

Introduction

I have been asked to tell you today about the pre-college educational program currently being carried out by the American Association of Physics Teachers (AAPT), the American Institute of Physics (AIP), and the American Physical Society (APS). As I prepared for this talk, I realized that there are just too many projects to even mention them all in the time allotted. As a result, I will briefly refer to a variety of projects but choose only several to describe in more detail.

Let me start by saying just a word about the associations and some of the very important people who play major roles in carrying out many of these programs.

AAPT has a membership of 10,000 physicists, roughly 7000 college and university faculty and 3000 high school teachers. It holds 2 national meetings each year that are devoted to physics and physics education. The responsibility for carrying out most of the educational programs rests on the shoulders of Jack Wilson, the Executive Officer, who is aided by 15 area committees and countless volunteers.

APS has a membership of about 40,000 physicists located in industry, colleges and universities, and government labs. Most of APS's educational programs are carried out by Brian Schwartz, the Education Officer, who works closely with the APS Committee on Education and many volunteers.

AIP has as its membership 10 physics and astronomy professional societies. Don Kirwan has the responsibility for carrying out most of the AIP educational programs that I'll mention today. He works with an advisory committee and many volunteers.

Programs for high school teachers

I'll start by discussing some of the programs that benefit high school teachers directly.

The most successful program of this type has been the AAPT's Physics Teacher Resource Agents (PTRA) Program. This program had the dual goals of giving teachers additional physics an and physics teaching expertise and also training them as resource agents for their colleagues. Approximately 300 PTRA's were selected over a 3-year period form the nation's best physics teachers. They participated in intensive summer training programs and special follow-up sessions at AAPT national meetings. As part of the program they had to agree to give physics workshops for other teachers in their regions. The outcomes of this program have included the following:

- Each PTRA has given an average of 5 workshops/year reaching an average of 125 participants.

The author is President of AAPT and Professor of Physics at West Virginia University, Morgantown, West Virginia 26506-6023.

- There exists a group of teachers with unsurpassed enthusiasm.
- A network of physics-teacher colleagues has replaced isolated teachers.

This program was supported by a 3-year grant from NSF which ended recently. Ways to continue this program are currently being planned.

Another exceptional success story has been the Local Physics Alliances Program sponsored by the joint APS/AAPT College-High School Interaction Committee. The goal of this project has been to improve physics teaching through school-college collaborations. To date, four regional workshops have been held with participants from 28 states. These 1 1/2-day workshops have been centered in the following regions:

- North Carolina/South Carolina/Virginia
- Indiana/Kentucky/Ohio/Illinois
- Oklahoma/Arkansas/Missouri
- Idaho/Utah/Washington (satellite workshop)

More than 500 physics educators have been exposed to the concept of local physics alliances and more than 70 new local physics alliances have been formed. This program has been funded by a 3-year grant from NSF. Continuation of this program, including more regional workshops, is being planned.

Other programs for teachers include:

- Numerous workshops at all AAPT meetings. These include topics such as the use of computers and video disks in teaching physics, physics demonstrations, and ways of improving physics labs.
- ASP's "Teachers' Days" at APS meetings. Local teachers are invited for day-long special programs that they help plan.
- AAPT's High School Teachers' Grants for Innovative Physics Teaching.
- Professional society participation in the Presidential High School Science Teachers Awards Program.
- AAPT's co-sponsorship of international conferences that include high school physics teachers and topics of key interest to them. Examples are the Inter-American Council Conferences on physics teaching held in Mexico in 1987 and to be held in Venezuela in 1991, and the U.S.-Japan-China Conferences on physics teaching held in Hawaii in 1989 and to be held in Japan in 1991.

Programs for high school students

Here I want to highlight the extremely successful, joint AAPT/AIP/APS international Physics Olympiad Program. 1990 is the fifth year of US participation in this 21-year old competition that typically involves 30 countries and some 150 students. The US team consists of 20 students who go through an intensive 1-week training program. They are selected by a three-step process. The first step is an exam that is open to all high school students and is taken by about 600 students. Next, the top 80 students are asked to take a second exam, and finally, the team is selected from among the students with the top scores in this exam. Finally, 5 students from the team are selected to go to the international competition. Last year (1989) a US team member was the top competitor and won the 1st US gold medal. This program has received major funding from AAPT, APS, AIP, AT&T Foundation, Eastman Kodak, Ford Motors, Hewlett-Packard, IBM, ONR, and Xerox, and additional funding from many other sources.

I'd like to urge all of you to contact AAPT, AIP, or APS and offer your assistance

Other programs for high school students include:

- AAPT's "Physics Bowl" (formerly Metrologic) competition in which some 1200 and more than 22,500 students participated this year.
- APS's Corporate Minority Scholarship Program
- AAPT's International Science Fair Awards.
- AAPT's Russian-US student exchange program.
- AAPT's "Outstanding Physics Student" Certificates that are awarded by local teachers.
- *Quantum Magazine* (with NSTA).
- The current development of a joint AAPT/AIP/APS "Phys Com" (Physics in the Community), a year-long physics course for *all* students that would be similar to the successful Chem Com course developed by ACS and would tie in with AAAS's Project 2061 goals.

Programs for pre-high school teachers and students

A very important program at the pre-high school level has been AIP's Operations Physics Program. This project, which was modeled after the PTRA Program discussed above, is aimed at training teams to work with teachers of grades 4-8. Its primary goals is to improve conceptual understanding of basic physics concepts. Three member teams consisting of a university faculty member, a state or district supervisor, and an outstanding elementary or secondary school science teacher, have been established in more than 40 states. These teams have already given more than 20,000 workshops. An evaluation of Operation Physics has found that teachers impacted by the program are teaching more physics and teaching it better. This project has been funded by a grant from NSF and by other federal and state grants.

Some other pre-high school programs are:

- AIP's Project SEEP (Students Explore and Experience Physics) in which teachers and student shear lectures and perform experiments at special sessions held during member society meetings.
- Wonder Science, a children's science magazine that is jointly sponsored by AIP and ACS and distributed through many schools.
- A joint AAPT-ACS program to evaluate teaching materials for elementary school physical science.
- AIP's Project SEER (Science Education and Equity Reform) which has run a pilot project in St. Louis aimed at improving science education and teaching science in ways that attract girls and minorities to careers in science.

Conclusion

As can bee seen from this short summary, physics professional societies are working in many ways to attempt to improve pre-college science education. Clearly the effort is large but not nearly enough. Almost all of the projects I have mentioned rely heavily on volunteers. The more people who are willing to volunteer their time to help, the greater the impact these projects will have. I'd like to urge all of your to contact AAPT, AIP, or APS and offer your assistance.

Symposium: Missile Technologies and Nuclear Arms Control

The following papers are based on talks given at another Forum-sponsored session at the April 1990 APS meeting in Washington, DC. Unfortunately, I was unable to get manuscripts from Bob Dietz, who spoke about "Depressed Trajectories, Short Time-of-Flight, Low Burnout, and Fast-Burn Boosters," and Robert Sherman who spoke about "Deterrence Through a Comprehensive Ballistic Missile Flight-Test Ban." Sherman's talk was however accompanied by a lengthy printed abstract, which we reprint here. *Editor*

Arms Control and Breakout from Nuclear Arms Treaties

Michael I. Sobel

The need for arms control

In light of the dramatic changes in the international scene, the democratrization of eastern Europe and the dissolution of the Soviet threat to the West, the question may be raised: Is there any longer a need for arms control? At present a number of important negotiations are in progress: the bilateral START talks on reductions in strategic weapons and the Conventional Forces in Europe (CFE) talks on reductions in conventional forces in Europe. Assuming successful conclusion of these negotiations, there will still remain important areas where arms control can reduce the risk of nuclear war:

Proliferation. The Non-proliferation Treaty is being reviewed in 1990 and must be formally extended in 1995. A number of important nations are not signatories (Pakistan, Israel, South Africa), and there is concern that a number of nations are seeking nuclear weapons capability. It is not clear that the non-proliferation regime, which explicitly recognizes two classes of nations, can be maintained indefinitely.

The question may be raised: Is there any longer a need for arms control?

START. This treaty will reduce the number of strategic warheads by about 30%. Nevertheless, the superpowers will be left with a total of about 17,000 warheads, multi-warhead missiles will not be outlawed, and several new deployments remain in the pipeline, including the US Trident II submarine-launched missile, the Soviet upgraded Blackjack bomber, and nuclear-armed sea-launched cruise missiles.

Warheads. There is no plan for destruction of warheads, destruction of fissile material, or limitations on production of fissile material.

Weapons in Europe. The NATO summit (July, 1990) reasserts the necessity for nuclear weapons in Europe (though to be used only as a "last resort"), but signals a willingness to eliminate nuclear artillery bilaterally.

Naval nuclear weapons. There are no discussions on nuclear disarmament in this area.

Command and control. Permissive action links are not installed on warheads carried on strategic submarines. Command-destruct mechanisms, which could destroy missiles in flight in case of accidental launch, are not currently used. The revised US targeting plan, according to a recent report (1), calls for prompt attacks on Soviet command centers. Research in anti-satellite warfare continues (2), and there is little progress toward a treaty banning anti-satellite weapons.

Firebreak. Developments that could weaken the separation between nuclear and conventional warfare include accurate long-range conventionally armed missiles that can strike a nuclear target; the US Navy's strategy of seeking out Soviet strategic submarines; proliferating capabilities in ballistic missiles and in chemical weapons, and the concept of nuclear weapons as a counter to that threat.

Rather than eliminating the need for arms control, the reduction in east-west tensions provides an opportunity for accomplishments that might not have been possible in the past.

Need for Stability

A central arms control objective is stability, in the sense that states are strongly constrained against use of nuclear weapons, and that this constraint remains strong whether international relations are friendly or not. Three different modes of instability may be classified, roughly according to time scale:

Crisis instability (a period of days or weeks). Two sides feel their vital interests are at stake and in conflict. Each side feels some risk that the other side will make a preemptive strike, feels some pressure to attack first, or to take a smaller step to protect itself (such as increasing alert levels), a step that may appear provocative to the other side. Such issues are relevant also to the risk of war by accident (unauthorized or unintended use of a nuclear weapon). For in such an event, the chance of its escalating to a larger scale use of nuclear weapons is quite small under conditions of crisis stability, but increased under conditions of instability.

Breakout instability (a period of months or years). One side feels incentives to break out of the nuclear balance (established bilaterally or otherwise) by clandestinely increasing its offensive capability, or weakening the other side's capability. In the event of a crisis it would be found to hold an unexpected superiority.

Arms race instability (a period of years or decades). One or both sides feel incentives to change the military balance and achieve superiority through planned (and largely open) programs of weapons building.

Stabilizing measures

Below are some examples of arms control measures that could play a role in enhancing stability, particularly stability against breakout from a situation of overall nuclear parity. These are given under the assumption that strategic nuclear deterrence remains a central element in relations among the major powers. While it is possible that either complete nuclear disarmament or effective total defense against strategic weapons may come about

Michael I. Sobel is on the faculty of the Department of Physics, Brooklyn College, Brooklyn, New York 11570.

at some future time, these possibilities still seem rather remote. At the least, a continuing regime of deterrence is likely for some significant period, and a variety of measures can support the stability of that regime:

> *At the least, a continuing regime of deterrence is likely for some significant period*

- A ban on ballistic missile defenses, such as the existing ABM Treaty, guarantees the effectiveness of ballistic missiles as a deterrent. Rapid deployment of anti-missile defenses is one of the breakout scenarios frequently discussed. The ABM Treaty prohibits testing of anti-missile defenses; it could be strengthened by closing loopholes that allow certain types of testing that might support development of anti-missile systems (3). One example is the testing of weapons in an anti-satellite mode, which is permitted under the treaty.
- While there may be technical means to distinguish anti-missile from anti-satellite testing, there is much to be said for a ban on anti-satellite weapons themselves. Destroying command and control components based on satellites would be an important precursor to a first strike.
- A ban on ballistic missile flight tests is discussed more fully in the other papers in this symposium. One of the options which has a good deal of support in both the US and the Soviet Union is a ban on depressed trajectory flights. Such flights can reduce the time of flight for ICBMs and for submarine-launched ballistic missiles. In the latter case they may represent a first strike threat to airfields, and thus possible nullification of the deterrent effectiveness of nuclear bombers. A second example is the maneuverable reentry vehicle, which to date had not been developed for long-range ballistic missiles, and would require testing. Maneuverable RVs represent a threat to mobile targets, either missiles or command centers. Mobility may become an important new means of guaranteeing (or enhancing) the survivability of elements of the deterrent.
- A low-threshold or complete ban on underground testing of nuclear explosives could halt a number of new weapons programs, including development of nuclear directed energy weapons.
- The most discussed breakout scenario has to do with the possibility of weapons being stored clandestinely and quickly brought out at time of crisis. One response is stricter controls on delivery vehicles. With greater acceptance of intrusiveness for verification, arms control agreements may include measures such as direct observation of the destruction of missiles, on-site inspection of weapons facilities (sometimes on short notice), continuous monitoring of production facilities, and overflights of national territories. A second response is controls on nuclear warheads. Examples are a system for dismantling nuclear warheads in a way that does not reveal design details, but that can be monitored by impartial inspectors (4); a plan for disposing of plutonium and reducing the enrichment of weapons grade uranium; and controls on the production of new fissile materials (5).
- While it appears that ballistic missile submarines will continue to be invulnerable for some time into the future, there may be a point where research with sonar, and other more exotic technologies, will provide effective means for locating submarines under the oceans. Thus, one may seek ways to guarantee the survivability of the strategic submarine force, for example, in sanctuaries specified by treaty.

> *It may also be that controls on research—something scientists instinctively reject—will be placed on the table.*

Finally, while technical means may be found to prevent breakout in a variety of ways over the next ten to twenty years, other methods of preventing the use of nuclear weapons will have to be found for longer time scales. These may be political (legal methods of adjudicating international disputes) and economic (elimination of poverty and economic disparities). Complete elimination of nuclear weapons may be the solution, along with technical controls on nuclear materials. It may also be that controls on research, something scientists instinctively reject, will be placed on the table.

References

1. Desmond Ball and Robert C. Toth, "Revising the SIOP," *International Security 14*, Spring 1990, p. 65.
2. Dan Fenstermacher, "The Decline of SDI and the Resurgence of ASAT," in Eric H. Arnett, ed., *New Technologies for Security and Arms Control* (American Association for the Advancement of Science, 1989), p. 105.
3. Ashton B. Carter, "Testing Weapons in Space," *Scientific American* , July 1989, p. 33.
4. Theodore B. Taylor, "Verified Elimination of Nuclear Warheads," *Science and Global Security*, Vol. 1, No. 1, 1989, p. 1.
5. Frank von Hippel, "Controlling Nuclear Warheads," in Frank von Hippel and Roald Z. Sagdeev, eds., *Reversing the Arms Race* (New York: Gordon and Breach, 1990, reviewed in this issue), p. 51.

Short Time-of-Flight Nuclear Weapons

Lisbeth Gronlund and David C. Wright

Introduction

While relations between the United States and Soviet Union are improving dramatically, there are several ongoing and potential developments in strategic weaponry that are incompatible with mutual security. For example, military developments may increase the capability to launch short time-of-flight (STOF) nuclear attacks against the nuclear arsenal of the other country. STOF systems include SLBMs fired at short ranges, and depressed-trajectory (DT) SLBMs, which could achieve considerably shorter flight times than standard SLBMs by following much lower trajectories.

In this paper, we focus on DT SLBMs and their possible role in STOF attacks. We present results of our calculations on DT SLBMs, briefly discuss the vulnerability of nuclear forces to current and possible future STOF capabilities, and mention some arms control measures that could mitigate the effects of STOF capabilities and prevent their further development.

Short time-of-flight attacks

The vulnerability of key components of the strategic arsenals to nuclear attach would depend sensitively on the amount of warning received, and this has given rise to concern about STOF nuclear attacks. The standard STOF attack scenario assumes an attack against bomber bases, command and control centers, communication nodes, and ICBM fields, with the goals of both destroying bombers before they can escape and ICBMs before they are launched, and of severely crippling the political and military command structure and communication network.

Assuming for the moment that capabilities exist to launch a STOF attack, one can assess their strategic importance. First, a disarming first strike is impossible with or without STOF systems. Such an attack would be enormously complex and demanding even if an adversary's entire arsenal could be attacked; it is futile given the invulnerability of current US and Soviet ballistic missile submarines.

However, independent of the actual capabilities provided by STOF systems, such systems could be destabilizing if political or military leaders misunderstood or overestimated their military capabilities and/or implications. Perhaps the greatest concern about STOF capabilities is that the country facing a STOF threat might react by making policy changes that would be destabilizing, such as explicitly adopting a launch-on-warning policy (if it had not already done so) and instituting shortened time-lines for decision-making during crises, which would decrease negative control.

Apart from the effects these weapons could have on stability during a crisis, the acquisition of STOF capabilities may provoke costly military expenditures by bout countries in an attempt to counter these capabilities.

Technical aspects of DT SLBMs

For each flight range, there is a unique ballistic missile trajectory that is the most energy efficient, which is known as the minimum energy trajectory (MET). These trajectories have the feature that they carry the missile very high above the atmosphere. If flown over less than maximum range, an SLBM can use its excess fuel to fly on less energy efficient, lower apogee trajectories. SLBMs flown on such depressed trajectories could have significantly shorter flight times than SLBMs flown on the minimum energy trajectory for that range.

Although neither the US nor USSR currently appears interested in developing DT SLBMs, it is important to assess how long it would take either country to develop such a capability should it decide to do so. It is particularly important to determine whether flying an SLBM on a depressed trajectory would require developing a new booster and/or reentry vehicle (RV) to withstand the increased stress on the booster and increased heating of the RV that would result form the longer time a DT SLBM would spend in the atmosphere. If not, acquiring a DT capability would likely require only flight testing of existing boosters and RVs on the new flight path.

In order to assess whether current SLBMs would be capable of flying on depressed trajectories we constructed a model of an SLBM based on the US Trident II D-5 missile, which has a maximum range of roughly 7400 km carrying eight 475 kT RVs, and roughly 11,000 km carrying twelve 100 kT RVs. We then calculated the loading and heating for several different depressed trajectories (see Figure 1) and compared them to the loading and heating for the standard maximum range trajectories that the Trident II is designed to fly. By basing our analysis on such a comparison, we avoid having to know what the actual stress and heat tolerance limits are for the Trident II and our results do not depend on whether we have modeled all the physical characteristics of the Trident II exactly.

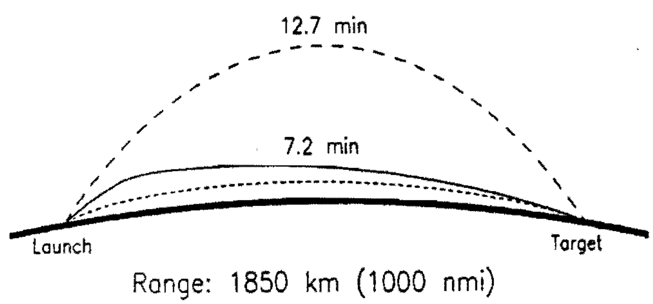

Figure 1. This figure shows three trajectories with a range of 1850 km for the model described in the text. The dashed curve is the minimum-energy trajectory (MET); the solid curve is the

Lisbeth Gronlund is at the Center for International Security Studies, University of Maryland, College Park. David C. Wright is with the Federation of American Scientists, 307 Massachusetts Avenue, N.E., Washington, DC. *Portions of this article are excerpted from a chapter in* Science and International Security: Responding to a Changing World, ed. Eric Arnett *(Washington, DC: AAAS, forthcoming). The authors would like to thank George Lewis and Ted Postol for valuable discussions, and each acknowledges the support of an SSRC-MacArthur Foundation Fellowship in International Peace and Security, awarded by the Social Science Research Council.*

low-stress depressed trajectory (DT) described in the text; the dotted curve is another depressed trajectory. The flight times are 12.7 minutes for the MET, and 7.2 minutes for each of the DTs.

Our model is two-dimensional, assumes a round, non-rotating earth, and includes the earth's atmosphere, which is the source of the loading and heating. The forces acting on the missile are gravity, the drag force due to the atmosphere, and before burnout, the thrust of the booster.

Aerodynamic loading. The aerodynamic loading on the booster is proportional to the atmospheric density along the trajectory and the square of the missile velocity. Flying a depressed trajectory such as that illustrated by the lowest curve in Figure 1 results in an aerodynamic loading that is substantially greater than that for the standard maximum-range trajectory the Trident II is designed to fly (see Figure 2). However, the aerodynamic loading on the booster could be kept at an acceptable level for a DT SLBM by flying a standard boost trajectory until the missile reaches altitudes (roughly 100 km) at which the atmospheric density is very small. The missile could then be turned sharply to flatten the trajectory with negligible loading. For this particular depressed trajectory (which we will refer to as the "low-stress" DT; see Figure 1) the loading on the booster would be essentially identical to that for an SLBM flown on a standard maximum-range trajectory (see Figure 2).

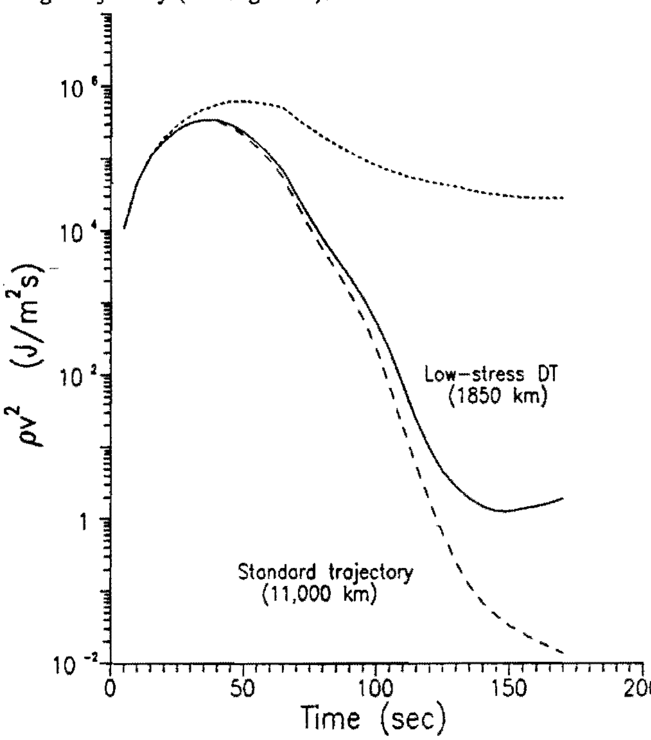

Figure 2. A comparison of the aerodynamic loading on the booster for the two depressed trajectories in Figure 1 and the standard 11,000 km minimum energy trajectory that a Trident II SLBM is designed to fly, for the model described in the text. The solid and dotted curves correspond to the solid and dotted trajectories in Figure 1, and the dashed curve to the standard trajectory. Note that the loading for the low-stress DT follows that of the standard trajectory, whereas the loading for the other depressed trajectory remains high throughout its boost phase.

Table 1. Flight times and apogees of SLBMs flown on minimum energy and depressed trajectories, for the model described in the text.*

Range (km)	Trajectory	Time of flt (min)	Apogee (km)
1850	minimum energy	12.7	450
1850	depressed	7.2	110
3700	minimum energy	19.0	860
3700	depressed	12.0	180

*The DT flight times are for the low-stress trajectory described in the text; flying trajectories that are further depressed would result in high loading on the booster and would have a negligible effect on the flight times. Flight times can be reduced slightly by off-loading warheads (off-loading all but one warhead reduces the DT flight time by about 30 seconds for the 1850 km case).

Flight time. The flight time for our Trident II model on the low stress depressed trajectory is roughly 60% of the flight time of a minimum energy trajectory over the same range, for ranges of less than 4000 km (see Table 1). Moreover, we find that attempts to shorten the flight path by flying a more depressed trajectory do not appear to reduce the flight time appreciably because of the increased atmospheric drag. The flight time could be decreased somewhat below that of the fully-loaded low-stress DT by reducing the payload (see Table 1), or designing a booster with greater total thrust. However, since atmospheric drag increases as velocity squared, flight times decrease very slowly with increasing thrust.

Heating of the reentry vehicle. The heating of an RV on reentry is proportional to the atmospheric density along the trajectory and the cub of the RV velocity. While the heat generated on reentry is greater for depressed trajectories than for a minimum energy trajectory of the same range, RVs for current SLBMs are designed to be used for ranges of 7500-11,000 km. Our calculations show that the total heat absorbed by an RV on standard trajectories over these ranges is comparable to that absorbed on depressed trajectories of less than 3700 km, the range over which DT SLBMs would likely be flown. On the basis of these calculations, we conclude that existing SLBMs could be flown on the low-stress depressed trajectory without incurring excessive stress on the booster or heating of the RV.

There are several developments in strategic weaponry that are incompatible with mutual security

Accuracy of depressed-trajectory SLBMs. Flying SLBMs on depressed trajectories would decrease their accuracy for two reasons. First, since an RV would spend more time in the atmosphere on a depressed trajectory than on a minimum-energy trajectory, it would be affected more by unpredictable variations in atmospheric density and winds. Second, due to the geometry of the flatter trajectory, guidance system errors (in burnout speed and angle) would lead to larger range errors for trajectories of the same range. Our preliminary estimates show that the range errors of a DT SLBM might be increased by a factor of 10-50 over that of an SLBM on a standard trajectory.

Depressed trajectory SLBM attacks on bomber bases

Bombers are soft targets that rely on quick escape for their survivability, and considerable effort has gone into ensuring that bombers can take off quickly after the first indications of an attack. The US keeps about 30% of its bomber fleet on airstrip alert, and these bombers are usually assumed to be able to escape within 7-10 minutes of tactical warning. Soviet bombers are not kept on day-to-day alert, but would be placed on alert during a crisis (1). Soviet bomber escape times are presumably comparable to or longer than those for US bombers. The 15 US bomber bases are distributed roughly evenly from about 100 to 2000 km from either coast or the Gulf of Mexico. The majority of the 20-25 Soviet bomber bases are west of the Ural Mountains and lie within about 2200 km of the nearest coast.

As discussed above, flying an existing SLBM on a depressed rather than a minimum-energy trajectory of 1850 km could reduce the flight time from about 13 to about 7 minutes, and thereby shorten the warning time from greater than, to comparable to or less than, the time required for a bomber to escape for a large fraction of the US or Soviet bomber forces. SLBMs capable of slightly shorter DT flight times than this might be required to attack the bombers based farthest inland.

Although the accuracy of existing SLBMs flown on depressed trajectories would be seriously degraded, bombers are typically assumed to be disabled by overpressures of 2-5 psi, which can be produced at relatively large distances from a nuclear blast. Warheads of 100 to 500 kT can produce these overpressures at distances of 1.5 to 5 km against bombers flying at altitudes of several kilometers, and a roughly twice these distances for bombers on the ground (2). If accuracies of DT SLBMs are degraded by a factor of ten to fifty, then the more accurate US and Soviet SLBMs are probably adequate for this mission, although the accuracy of most Soviet SLBMs may be marginal or inadequate. The development of precision-guided maneuvering RVs (PGRVs) combined with a DT capability could provide both high accuracy and very short flight times. The US has funded a small strategic maneuvering RV research and development program for many years, but the development of PGRVs for strategic warheads faces numerous technological hurdles and would require an extended research, development, and testing program (3).

SLBM attacks on hard targets

Highly accurate SLBMs, if launched on minimum-energy trajectories from submarines stationed close to shore, could provide hard-target kill STOF capabilities against targets far inland. The flight time of an SLBM on a minimum energy trajectory of 3000 km is less than 16 minutes; the minimum time required for the US to detect an attack and launch its ICBMs is believed to be roughly 15 minutes (4). In early 1990, the US began deploying the Trident II D-5 SLBM, whose CEP of 130 meters and 475 kT warheads give it a high kill probability against hardened targets.

Arms control measures to limit the attainment of STOF capabilities

Various types of restrictions on the flight testing of SLBMs could help curtail the capability to launch STOF attacks.

Banning flight testing of SLBMs on depressed trajectories would prevent proof-testing of existing SLBMs on depressed trajectories. Since current SLBMs appear capable of flying depressed trajectories with significantly reduced flight times, the long flight-testing program required to develop a new missile or RV would probably not be needed to attain considerable DT STOF capabilities. Thus, the breakout time from a treaty prohibiting flight testing might be relatively short. However, a series of flight tests would still be required in order to gain confidence in the system and evaluate its accuracy, especially if it was to be used in a first strike. Moreover, a ban on the flight testing of DT SLBMs would prevent the development of new missiles designed specifically for DT flights, which could reduce flight time seven further and thereby potentially threaten all the bombers in the US or Soviet forces.

A ban on the flight testing and deployment of new SLBMs would prevent the acquisition of new SLBMs with hard-target kill capability, and SLBMs designed specifically for depressed trajectories. Since the US is already deploying a highly accurate SLBM, the Trident II, such a ban should be combined with either the destruction of deployed Trident II missiles or a freeze on further deployment.

Prohibiting flight testing of all SLBMs would erode the level of confidence in SLBM reliability, which would decrease confidence in the ability to carry out a demanding operation such as a first strike STOF attack much more than it would decrease confidence in the ability to retaliate.

Since accuracy is an important component of STOF capabilities, prohibiting the development of PGRVs for strategic weapons would prevent STOF capabilities from becoming more threatening. This could be accomplished by a ban on flight testing of such RVs.

Conclusions

It is in both the US and USSR's interest that neither country attains appreciable STOF capabilities, and further that both countries make explicit their intention not to pursue such capabilities. Both of these goals can be attained through a combination of the arms control measures discussed above. The US and USSR should take advantage of the end of the cold war to reduce significantly their military spending and codify a more stable strategic relationship through arms control. Given the new climate in US-Soviet relations, such a move toward mutual security should now be achievable.

Notes and references

1. Stephen M. Meyer, "Soviet nuclear operations," in *Managing Nuclear Operations*, ed. by Ashton B. Carter, John D. Steinbruner, and Charles A. Zracket (Washington DC: The Brookings Institution, 1987), p. 494.
2. Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., (Washington DC: US Government Printing Office, 1977), pp. 104-115.
3. See, e.g., Matthew Bunn, "The next nuclear offensive," *Technology Review* January 1988, p. 28.
4. This time can be inferred from, Ashton Carter, "Assessing command system vulnerability," in *Managing Nuclear Operations*, p. 581; and John Steinbruner, "Launch under attack," *Scientific American* January 1984, p. 37.

Deterrence Through a Comprehensive Ballistic Missile Flight-Test Ban

Robert Sherman

Because a complete ballistic missile flight test ban (BMFTB) would at one stroke contain or eliminate three of the five major components of a disarming first strike, it offers the most effective means to maximize crisis stability. The primary purpose of both control and deployment of strategic nuclear arms is to create crisis stability by deterring the other side's use of its nuclear arms. Strategic nuclear arms control should thus be created by following this sequence: (1) *identify the assets* that deter attack; (2) *identify the threats* that could disable those assets; (3) *negotiate controls* on those threats.

The primary purpose of strategic nuclear arms is to create crisis stability

The strategic nuclear weapon properties that most directly threaten to enable a first strike and undermine deterrence are: *accuracy* to destroy hard silos and C^3; *surprise* to destroy unlaunched bombers and ICBMs as well as soft C^3; *high warhead/silo ratio* to enable an ICBM counterforce exchange to favor the aggressor; *strategic anti-submarine capability* to pre-empt against that leg of the victim's triad; *weapon reliability* to give the aggressor confidence in his ability to minimize retaliation. All five ingredients are necessary for a disarming first strike. Under rational leadership, absence of only one of these ingredients would be sufficient to deter. But since national leaders are not always rational, the more first-strike ingredients that can be controlled, the lower the probability of strategic nuclear war.

Strategic arms controls now in force or under negotiation have negligible impact on any of the five ingredients. A CTB would impact only reliability. A total MIRV ban would impact only warhead/silo ratios. START will have no appreciable effect on any of the five.

But a BMFTB would impact accuracy, surprise, and reliability simultaneously. Partial BMFTBs can also be useful only if they flatly prohibit specific types of tests, e.g. MIRV, MaRV, or depressed trajectory. Partial BMFTBs that permit annual quotas of first-strike weapon tests would be of little use because they would only marginally retard improvements in accuracy and surprise, and would have no effect on reliability. Similarly, a BMFTB on tests of new weapon types, which permitted tests of existing types, would be of little use without a radically restrictive definition of new types.

Verification of a BMFTB requires several different techniques of varying difficulty. The most troublesome danger of cheating comes not from hiding tests which is very difficult to do, but from subsystem tests disguised as space flights. It is essential that a BMFTB establish a firm wall between missile tests and space flights. The wall is easy to build for the reentry phase, by simply prohibiting high-speed reentry. It is also easy, albeit more expensive, to build the wall for the boost phase by prohibiting flights of boosters sharing gross physical characteristics with strategic missile boosters.

The most difficult task for a BMFTB is to prevent improved missile guidance systems from being tested in space vehicles. This would probably require highly intrusive and cooperative measures. It could, however, be left to a BMFTB 2 since guidance upgrades would be of little use to a war planner unable to test the interface of his new guidance system with the rest of the missile, and unable to determine if his reentry vehicles are able to retain the accuracy of his guidance system.

If a BMFTB is viewed as a deterrent weapon, it has the unique property of improving with age.

The author is a Congressional Aide at the US House of Representatives, 2159 Rayburn House Office Building, Washington, DC 20515.

REVIEWS

Reversing the Arms Race: How to Achieve and Verify Deep Reductions in the Nuclear Arsenals, edited by Frank von Hippel and Roald Z. Sagdeev

Gordon and Breach, New York, 1990, 352 pages, $40 hardcover, $20 softcover

The end of the cold war has raised hopes that the superpowers will at long last succeed in slashing their huge nuclear arsenals. The START Treaty, reported to be nearly complete, will be only a modest step in that direction, as each side will be allowed to retain some 9000 strategic warheads. Even before the completion of START, attention has turned to the possibility of much greater reductions.

In February 1987 the Federation of American Scientists and the Committee of Soviet Scientists for Peace and Against the Nuclear Threat undertook a cooperative research project to study the feasibility of deep cuts. The volume under review is a collection of papers stemming from that project; several of the papers have already been published in the new US-Soviet journal *Science and Global Security*. A paper by Harold Feiveson and von Hippel in the Summer 1990 issue of International Security also contains much of the same material. Although the participants held several joint workshops, only one chapter constitutes joint US-Soviet work.

Most of the book is given over to technical studies of verification problems. Verification of limitations on sea-launched cruise missiles deservedly receives a great deal of attention. The SLCM problem plagued the START negotiation and was finally set aside unresolved, primarily because of verification difficulties; a solution will have to be found if further progress is to be made. Some constructive ideas are presented here, although the suggested verification schemes contain elements that have already been rejected by, and are likely to remain unacceptable to, the United States.

Another useful set of papers addresses the problem of verifying nuclear warhead reductions, including the fissile material. Such provisions are not part of any previous treaty, but will have to be included in a deep cuts agreement.

The verification studies will appeal primarily to the specialist. Of greater interest to the general reader will be two papers, one by Soviet authors Sagdeev and Kokoshin and the other by Americans Feiveson and von Hippel, entitled "Stability of the nuclear balance after deep reductions." Both papers analyze a balance in the range 2000-3000 strategic warheads on each side; the Soviet authors study also a more ambitious regime with 95% reductions from present levels (i.e., to about 600 warheads). The studies are based on conventional exchange calculations; the paper by the Soviet authors is short on details, both as to methodology and as to the force structures assumed.

Both studies conclude that forces at the level of about 2000 warheads, if properly configured, would be stable in the sense that neither side could carry out a disarming first strike. The principal feature of the reduced forces is that MIRVed ICBMs have been phased out; these are generally held to be the most destabilizing strategic weapons. However, the conclusions of the Soviet study point up some of the difficulties likely to confront any attempt to negotiate deep cuts. The authors find, for example, that deployment of ballistic missile defenses would lead to instability even if the defensive system has very low effectiveness (30-50%). This suggests that agreement not to deploy defenses is a prerequisite to deep cuts, a position taken by Soviet negotiators at START.

The Soviet analysts find strategic stability to be even more sensitive to antisubmarine warfare (ASW) capabilities. If deep cuts are to be achieved, they conclude, it will be necessary to take measures to significantly increase the survivability of ballistic missile submarines—for example, by creating sanctuary zones in which ASW activities are banned.

These suggestions may be quite sensible, but their negotiability is doubtful. The Reagan administration's refusal to accept restrictions on SDI nearly scuttled START, and President Bush seems committed to deployment of some kind of defense. As for antisubmarine warfare, the US has always been substantially ahead in that area and has shown little interest in ASW arms control of any kind.

In their analysis of 95% reductions, the Soviet authors find that the most stable force structure consists of 600 small single-warhead ICBMs on each side, some deployed in fixed silos and some on mobile launchers. All submarine-launched missiles and bomber weapons are eliminated. The authors must recognize that this is not a realistic proposal. It is inconceivable that the United States, which relies heavily on SLBMs and bombers, would agree to scrap them as part of a deep cuts treaty.

If I have a complaint about the book, it is that the title promises more than the contents deliver. There is a lot about how to verify deep cuts, but very little about the more difficult problem of how to achieve them. The principal obstacle to deep cuts, in my judgment, is the mission assigned to the nuclear arsenals. Current US strategy requires us to hold at risk virtually the entire Soviet military capability, both nuclear and conventional, as well as a substantial number of high-value industrial/economic targets. That mission generates a set of 5000 or more primary targets, many of them cross-targeted by more than one weapon. Gen. John Chain, the outgoing commander of SAC, has testified that he will need every one of the warheads allowed under START in order to carry out his mission. If substantial additional reductions are to be acceptable, the target set itself must be drastically cut back.

The 5000+ target set is based on scenarios that have no relevance to today's dramatically changed political/strategic environment. The threat of a Soviet attack, in Western Europe or anywhere else, has all but evaporated. Military targets in the Warsaw Pact states are disappearing as Soviet forces are withdrawn from those countries. If deep cuts are implemented, many strategic targets will disappear as well. Within the context of a deep-cuts treaty, target sets on both sides can safely be slashed by an order of magnitude. But persuading the military leaderships of that will not be an easy task.

Leo Sartori
Professor of Physics
University of Nebraska
Lincoln, NE 68588

NEWS

To Bill Havens from the Forum: Thanks

The following citation of thanks from the Forum was read to Bill Havens at his retirement banquet at the Urbana APS Council Meeting:

Bill, the entire APS owes you a great debt of gratitude for guiding the APS over these many years. You have handled the many problems, both small and large, with great wisdom, clarity, and patience. We will continue to need your guidance and good memory in the future, so please stay infolded in APS matters. The Forum on Physics and Society, in particular, would like to thank you for helping us grow in directions that have facilitated the honest debate of the science aspects of public policy issues. Your wisdom and guidance have been extremely valued on this big and important task. Our best wishes to you at your retirement banquet.

Kudos for *Physics and Society*

At the APS Council meeting on 28 October, the Council unanimously approved the following citation:

Resolved: That the Council of the American Physical Society commends Professor Art Hobson, University of Arkansas, for his outstanding development of the Newsletter of the Forum on Physics and Society. He has transformed it into a first-class quarterly of news and substantive articles. The Council recognizes Professor Hobson's successful efforts to enhance the value of Physical Society membership through the creation of this excellent medium of communication with the members of the Forum.

The Cincinnati Meeting: Three Forum Invited Sessions

Look for these three excellent Forum-sponsored invited sessions at the APS meeting in Cincinnati, 18-22 March. Join in the discussion! The physics community needs to help sort out these problems:

- "The Role of the National Labs," organized by Barbara Levi.
- "A Blue Ribbon Discussion on Physics Education," organized by John Russell and co-sponsored by the APS Committee on Education. We hope that this panel will include some of the Nobel laureates who have recently been active in physics education.
- "The Role of the States in Funding Physics Research," organized by Ruth Howes.

The Washington Meeting: Contribute a Paper to the Forum's Session!

If you hurry, you might still be able to make the deadline for contributed papers at the APS Spring meeting in Washington DC, 11 January! Consider giving a paper at the Forum's contributed session. Physics and society issues are surely sufficiently worthy of the physics community's professional time to warrant at least one contributed session per year. Get involved! Contribute a paper! We need to establish the continuing precedent of a contributed paper session every year, and we can do so only with your help. Specify to APS that your paper should be included with the Forum's physics and society session.

And in any case, support the session with your attendance!

The Washington Meeting: Global Warming Short Course!

[In case you're wondering "why all the exclamation marks?" —they represent exhortations for you, dear reader, to take some action.]

Come early to the APS Spring meeting to learn from the experts the facts and theories behind predictions of climate change that might be caused by increased inventories of greenhouse gases! The short course will be held on Saturday and Sunday, April 20-21, in the physics department of Georgetown University. The tentative program includes V. Ramanathan (Scripps Institution of Oceanography), Thomas Ackerman and James Kasting (both of Pennsylvania State University), David Randall (Colorado State), Robert Cess (SUNY Stony Brook) and Art Rosenfeld (Lawrence Berkeley Laboratory). The course is being jointly sponsored by the Forum, the APS Panel On Public Affairs, the Georgetown University Program on Science and Technology in International Affairs, and the Georgetown University Physics Department. The registration fee of $100 will include a book compiled from presentations. For more information, contact Barbara Levi at *Physics Today*, 335 East 45th Street, New York, NY 10017.

The Washington Meeting: Forum Invited Sessions

The annual APS meeting in Washington, DC (or Baltimore) is always the big one for the Forum. This year, in addition to the above two items, we will have four invited sessions including: the yearly Awards Session, "Alternatives to Traditional Peer Review" organized by Rustum Roy, and "Protecting the Space Environment" organized by Joel Primack and co-sponsored by the Division of Astrophysics. The fourth session, and further details, will be announced in the April issue of *Physics and Society*. Also at this meeting, the Division of Astrophysics and the Forum will jointly sponsor a session entitled "The Future of Astronomy," dealing with issues such as NASA, and manned versus unmanned space ventures.

Call for Ideas: Forum Sessions, Forum Studies!

The Forum is always looking for ideas for invited sessions at APS meetings and for Forum-sponsored studies. We hope to sponsor an invited session at the Division of Nuclear Physics meeting in October 1991, as well as the March 1992, April 1992, and perhaps other, meetings. We need your suggestions for topics and speakers!

The Forum recently sponsored an energy study, which should be published very soon (look for it). There have been suggestions that we sponsor studies of (1) long-term global environmental changes including warming, ozone, and radioactive wastes, and (2) technologies that will shape future conventional weapons. Again, we need your input!

Send your thoughts and suggestions to: Ruth H. Howes, Forum Vice Chair, Department of Physics, Ball State University, Muncie, IN 47306, phone 317-285-8868, FAX 317-285-1624, Telemail RHowes.

Does Anybody Have Any Really Old Newsletters?

Even though we're only twenty years old, the Forum's institutional memory is already dimming with age. This newsletter is one good memory bank. But it's not clear that a complete set exists. The editor's file is complete only from Volume 11, beginning in January 1982. Missing are: Volumes 1 through 8 (entire), Volume 9 numbers 3 and 4, Volume 10 number 1. These ten volumes span the years 1972-1981. If anybody out there has any of these, please send a copy to the editor.

To Receive *Physics and Society!*

Physics and Society, the quarterly of the Forum on Physics and Society, a division of the American Physical Society, is distributed to members of the Forum and to physics libraries. Nonmembers may receive the newsletter upon request by writing to the editor; voluntary contributions of $10 per year are most welcome. Make checks payable to the APS/Forum.

Physics libraries may receive *Physics and Society* free upon request by writing to the editor. The Forum hopes that libraries receiving *Physics and Society* will archive it. Forum members should request that their libraries do this.

If you are an APS member it is easy to join the Forum and receive *Physics and Society*. Just complete and mail (either to the editor or directly to the APS office) the following form, or mail us a letter containing this information.

I am an APS member who wishes to join the Forum:

NAME (print) ______________________________

ADDRESS ______________________________

____

____

COMMENT

The Forum Enters Its Third Decade

The Forum turned 20 last year, and *Physics and Society* enters its twentieth year with this issue. Some reflection seems appropriate.

America in 1970 was torn by warfare abroad and near-revolution at home. Tragedy is a forceful teacher, and Vietnam was no exception. We all grew up a little.

For at least a few physicists, those forming the new Forum on Physics and Society, one of the lessons was that you never do just one thing. You never do just physics. This should come as no great surprise to physicists. After all, the quantum uncertainty principle teaches us that nature cannot be divided into independent parts, so that ultimately physics is a statement not only about nature but also about ourselves. Physics, like every other human endeavor, has its human, social and political implications. Physics confers knowledge, knowledge confers power, and power is always up for grabs. Thus the physicist bears some responsibility for the uses of the technologies of war. Such, at least, was the view of many "activist" scientists.

Martin Perl edited *Physics and Society* from its inception in 1972. As he turned the newsletter over to John Dowling, who then edited it until 1986, Perl commented in the April, 1980 issue, that "—the APS has finally become comfortable with the concept that it should be involved with physics and society issues such as the environment, arms control, and the economic welfare of physicists." Further, "*Physics and Society* and the Forum have contributed indirectly to the education of the public and public officials on environmental issues by stimulating and supporting the interests of physicists in those issues."

But 1980 was a dark time for scientists concerned about misuses of military technology. Afghanistan had been invaded, SALT II was dying a slow death, and a new hawkishness was evident in Washington. Perl commented that "Perhaps the unconscious reason for my passing on the editorship is that I don't feel I can energetically begin again with the arguments and issues of ten years ago."

As the Forum entered its second decade, then-Chairperson Brian Schwartz commented in that same April 1980 issue that "The Forum was one of the first groups to sponsor sessions on issues of science and society on a regular basis in the regular program of a professional science society. In the early 1970s this was unusual. In 1980, sessions on issues of science and society are common at professional society meetings."

Today, there is elation at the end of the cold war, but disappointment at continuing large military budgets. There is hope in the environmental awareness that produced for example a bold new clean air bill and meaningful international action on ozone depletion and global warming, but concern that we are not doing enough, that the nation is more concerned about quantity of profits than quality of life, and that our addiction to oil is driving events toward tragedy in the Middle East.

The Forum exists to promote discussion of such issues among one group that creates the ideas that affect the world so powerfully: the physicists. It is encouraging that the physics community and the APS have been so involved in these issues during the past decade. Important examples are the APS-sponsored Directed Energy Weapons study, and the Forum-sponsored sessions and workshops such as the one on global warming at the upcoming Washington DC meeting (see News, in this issue).

But more is needed. It is perhaps the characteristic error of our time that we all try to do "just one thing," especially we scientists, we who should know better, but we who are too-often mesmerized by our research specialties. Physicists who would rather not bother with the full context of physics are much like technology consumers who would rather not bother learning science. Both argue that "it's not my department." But it is our department, most especially for us physicists.

The "Newsletter:" Identity Crisis at Twenty?

What is this publication? Although it started as a newsletter, it has evolved into more than that. Yet it is not a "journal," for that would imply different standards than are appropriate for a publication dedicated more to discussion than to originality. "Quarterly" conveys an appropriate ambiguity, perhaps. The name problem stems from an identity problem: What should *P&S* be doing? As this publication enters its twentieth year, this deserves some thought.

The purpose of *Physics and Society* is to promote discussion of and involvement in physics-related societal issues and, as our organizational name implies, to provide a forum for such discussion. Thus *P&S* is a newsletter that informs readers of meetings, sessions, workshops, and books, but it is also a medium for substantial articles, letters, and comments.

This dual role raises questions: What is appropriate for publication? What about refereeing? How can *P&S* be relevant without propagandizing? How can balance be preserved?

My philosophy as editor has been to encourage the airing of ideas (primarily in the articles) and views (primarily in the letters and comments). Contributed articles are reviewed by at least one outside expert to check their overall technical correctness, but they are not heavily refereed.

Articles, letter and comments are published, regardless of their originality, if they are technically correct and if they appear sufficiently interesting to be worth the time of socially aware physicists. If an article leans far toward one end of some spectrum of opinion, I try to arrange to balance it with a contrasting view. And of course everyone is invited, in fact encouraged, to respond with letters and comments of their own.

I'd be happy to hear and publish your ideas about Physics and Society. And please do join other newsletter writers in our quest for fuller understanding at the interdisciplinary boundaries. Articles should be a short and sweet 2000 words maximum (technical details are encouraged), comments and book reviews should be under 1000 words, and letters under 500 words.

War And Oil

Worst case scenarios: Former Navy Secretary John B. Connally warns that war with Iraq would be "disastrous," inflicting US casualties "probably in excess of 50,000." If it breaks out, Connally says that the US should shorten it and save lives by using nuclear weapons, and "That's a cruel thing to say, but that's the most merciful thing to say."

Some US officials believe that an assault on Iraqi forces in Kuwait would prompt Saddam Hussein to attack Israeli population centers with long-lived anthrax or botulin toxins. One aim would be to rally the Arab world by dragging Israel into the war. "It would be a policy of genocide toward Israel," a US official said. "If done properly, —one plane could destroy 98% of the population over a period of three to five days."

Israeli Prime Minister Shamir has warned that Iraq will "pay a terrible price" for attacking Israel. Such statements are viewed by US officials as threats to retaliate with Israel's nuclear weapons.

Hussein is reported to have mined Kuwait's oil fields, with the apparent aim of burning his "bridges" behind him if it comes to that. And Iraqi biological or other assaults may be targeted on oil industry chokepoints in Saudi Arabia and the United Arab Emirates, to force industrial workers to flee and destroy oil pumping stations and terminals.

Finally, rumors continue to surface regarding Iraqi acquisition of high-tech lathes and centrifuge parts, suitable for nuclear weapons. Experts differ on how far Iraq is from having nuclear weapons, with predictions ranging from a few years (Israeli sources estimate 2 years to a working plutonium-producing reactor) to over ten years (Leonard Spector).

Against all this, place just one observation regarding the US appetite for oil: If mandated mileage standards had not been rolled back during 1986-88, new US cars could be averaging the 30 miles per gallon (mpg) that other countries get, instead of our present 26 mpg. Clearly, America's fleet average could easily be 5 mpg above our present miserable 18 mpg, and in line with the world's 23 mpg (which is still quite low). Assuming similar efficiencies in the remainder of the transportation sector (mostly trucks), this easy mileage improvement would by itself reduce oil consumption by over 2 million barrels per day. Total pre-crisis imports from Saudi Arabia, Iraq, and Kuwait combined were 1.8 million barrels per day.

These are important matters. They have a science component. By the time you read this, events may have pre-empted the question of war in the Mideast. *P&S* invites your thoughts.

Art Hobson