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LETTERS

NUCLEAR ORBIT-TO-EARTH MISSILES

Your September 1986 summaries of the two APS Forum sessions on the Strategic Defense Initiative (SDI) give an excellent overview of the current state of the ongoing debate on ballistic missile defense (BMD) with space-based components, the type most favored by SDI officials.

The Soviets have already indicated that such a defense would be countered by an anti-satellite (ASAT) force including relatively cheap "low-tech" maneuverable space mines for trailing BMD satellites and blowing them up on command. But a truly frightening prospect is that suitably designed space mines could also serve as nuclear orbit-to-earth missiles (NOEMs), using their maneuver rockets to de-orbit (as in the Soviet fractional-orbit bombardment system of the 1960s).

NOEMs are, of course, banned by the 1967 Outer Space Treaty, but Gorbachev warned, at the 1985 summit, that all arms control "will be blown to the winds" if a "Star Wars" defense (banned by the ABM treaty) is deployed.

If BMD satellites should turn out to be survivable in the face of an ASAT attack, so should NOEMs using the same survivability techniques, making them unstoppable by any non-terminal defense. If, on the other hand, NOEMs turn out to be non-survivable, so would BMD satellites, making their defense against ICBMs worthless. In either case, the offense will prevail.

NOEM survivability can be improved without any fuel loss by unpredictable orbit-changing mass exchanges between roughly co-orbital NOEMs using small nuclear powered mechanical or electro-magnetic mass launchers. NOEMs could also be accompanied by (free or tethered) decoys, and be salvage fused to explode on attack, with the resulting signal triggering space mines near enemy BMD satellites.

With only a third of their mass expended as rocket fuel, NOEMs could travel from a 200 km orbit to ground in about 3 min., with a 10-20 sec vertical fast-burn fuel exhaust velocity of 3 km/sec. Since modern positioning and arming systems (used before hostilities begin) could make them quite accurate, they would therefore have a highly destabilizing short-warning first strike potential, particularly if they are seen as vulnerable.

Finally, a purely ground based "pop-up" BMD could be decimated, e.g. in its own boost phase, by a "pop-up" anti-BMD, which can always be up first; or, if the BMD can be made unstoppable, so can any forward-based missile force.

Louis A.P. Balázs, Department of Physics, Purdue University, West Lafayette, IN 47907

CHERNOBYL

The Forum on Physics and Society tries to be alert to occasions in which seemingly esoteric investigations lead to conclusions that have a bearing on our ordinary lives. It therefore distressing that the authors of the pieces on Chernobyl in your January 1987 issue seem to be unaware of the scientific conclusion that "Planet Earth is made of nuclear wastes" (New York Times, July 22, 1986). The direct import of this conclusion is that members of the public are being exposed to controllable levels of ionizing radiation that make the exposures from Chernobyl seem modest by comparison.

The major exposure mechanism is indoor radon, initially thought to exist in U.S. homes at a nominal level of 0.8 pico-Ci/liter, but now believed to be somewhat higher on the average, and factors of five to fifty times higher in a significant fraction of U.S. dwellings. The U.S. EPA has recently issued a "guideline" for indoor radon (4 picoCuries/liter) which gives a cumulative whole body equivalent lifetime radiological exposure comparable not to the Chernobyl exposures in Sweden, but to the exposures in the 3 to 7 kilometer zone around the Chernobyl plant itself (reported by the Russians as 54 REM on the average). The virtually unanimous reaction of those affected by indoor radon (home owners, utilities involved in home modifications for purposes of energy conservation, and realtors facing radon liability litigation) is not only that the EPA guideline is "safe," but that the references on health effects of ionizing radiation cited by Barbara Levi are nonsense. This is what proponents of nuclear power have been saying all along, but home owners who don't believe that 4 picoCuries/liter of radon in their dwellings will cause death to one occupant in 33 may have more clout.

It is of course true that public opinion does not alter the actual dose-response curve for human exposure to ionizing radiation. But public opinion may encourage scientists who make learned pronouncements about the health effects of ionizing radiation to be less alarmist in their rhetoric and more forthright in placing radiological exposures from different sources in proper perspective.

Henry Hurwitz, Jr., 827 Jamaica Rd., Schenectady, NY 12309

Response:

I certainly agree with Mr. Hurwitz on the importance of placing various risks in proper perspective. That is precisely why I was careful in my article, "Estimating Long-Term Health Effects from Chernobyl: Some Useful Parameters," to compare the Soviet estimate of about 5000 long-term deaths from Chernobyl to the normal occurrence of some 9.5 million deaths from cancer in the same population. The intent of my article was not to alarm (and my language was certainly not "alarmist") but to inform. I aimed merely to provide useful data for conversion among the various radiation units being reported. For that purpose, I drew data from fairly standard, respected and accessible sources (my references 2 through 12). If Mr. Hurwitz has specific evidence to back his claim that those references are "nonsense," I would like to learn about it.

Barbara G. Levi, Center for Energy and Environmental Studies, Princeton University

ARTICLES

MANAGED VERSUS UNMANAGED 7 YEAR ELECTRIC GROWTH: CALIFORNIANS NEEDED 3 NEW PLANTS, TEXANS NEEDED 11 (1), by Evan Mills and Arthur H. Rosenfeld, Center for Building Sciences, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720

In the early 1970s, electricity demand in the U.S. was expected to continue to double every decade. By under-estimating the potential for conservation, planners and regulators approved the construction of far too many power plants. Had the projected growth materialized, today's $150 billion electricity bill would be far higher and customers would be paying more than they are now to cover construction costs for power plants they didn't need. Growth has declined primarily because conservation turned out to be far less expensive than new supply--3-5 times cheaper than new power plants. Today, energy-efficiency standards like those in California have stretched the demand doubling time from one to three decades, saving billions of dollars annually. However, progress has varied greatly among the states. California and Texas illustrate the effects of regulation versus laissez faire on conservation (2).

Using federal data and simple corrections, we can see how the normalized demand for electricity declines in California while it steadily increases in Texas and across the country. Progress in California has been hastened by mandatory building and appliance efficiency standards. The 1993 refrigerator standards alone (already partially implemented), compared to the 1977 refrigerator, will save 1,200 kWh/household or 15 BkWh for California--the equivalent of three, 1,000-MW base-load power plants. Other California standards and conservation programs target commercial and industrial customers. In contrast, Texas has left matters almost entirely to the marketplace and still has growth rates of 4.5%.

The data in Table 1 show that California, which has 11% of the U.S. population and 12% of the national income, consumes only 8% of the electricity, while Texas, which represents only 7% of national population and income, consumes 9% of the electricity. Californians use less than half as much electricity per dollar of gross state product (GSP) than do Texans, although both have had declining growth in kWh/$GSP. Texas' climate, construction activity, and industrial structure are different from California's. Nonetheless, the *rates* of electricity demand growth, normalized for population growth in the residential sector, floor area growth in the commercial sector, and value-added in the industrial sector, reveal the rewards of energy demand planning in California. The rates of electricity price increases are slightly higher in Texas.

Table 1. Economic Comparison of Texas and California (1984).

	Population (Millions)	%	Income ($B)	%	Electricity (BkWh)	%
US	236	100	3000	100	2278	100
CA	26	11	367	12	175	8
TX	16	7	202	7	208	9

Table 2. Normalized growth in electricity demand since 1977: CA, TX, and U.S. (4).

		U.S.	CA	TX
I.	TOTAL 1984 kWH/capita	9648	6838	13021
	•Δ(kWh/capita)1977-1984	782	-267	1424
	•Annual growth rate	1.2%	-0.5%	1.7%
II.	TOTAL 1984 kWh/$84 $1000 GSP	760	477	1030
	•Δ(kWh/$84 $1000 (GSP)'80-'84	-26	-80	-33
	•Annual growth rate	-0.5%	-2.2%	-0.4%
III.	RESIDENTIAL growth/capita '77-'84			
	•Δ(kWh/capita)	357	136	652
	•Annual growth rate	1.7%	0.9%	2.4%
IV.	COMMERCIAL growth/ft^2 '77-'83			
	•Δ(kWh/ft^2)	1.3	-0.2	0.4
	•Annual growth rate	2.0%	-0.4%	2.2%
V.	INDUSTRIAL growth/$ value-added '77-'83			
	•Δ(kWh/$82 value-added)	0.06	-0.08	0.14
	•Annual growth rate	1.5%	-3.0%	2.0%
VI.	1982 ENERGY PRICES (all sectors)			
	•Δ($82/kWh)1977-1982	$0.010	$0.016	$0.017
	•Annual growth rate	2.6%	3.6%	4.5%

During the seven-year period of 1977-84, the average Californian's electricity use decreased by 267 kWh while the average Texan used 1,424 kWh *more* than in 1977 (see Figure 1 and Table 2.) Industiral conservation efforts have been especially effective in California where, in 1982, energy costs represented only 3.5 cents of each dollar of value-added versus 4.5 cents and 7.1 cents in the U.S. and Texas, respectively. (The cogeneration of electricity and process heat may account for part of the differences between Texas and California). The sum of all the above effects is that during the seven year period California has built or acquired the electricity corresponding to three new plants and Texas eleven (3).

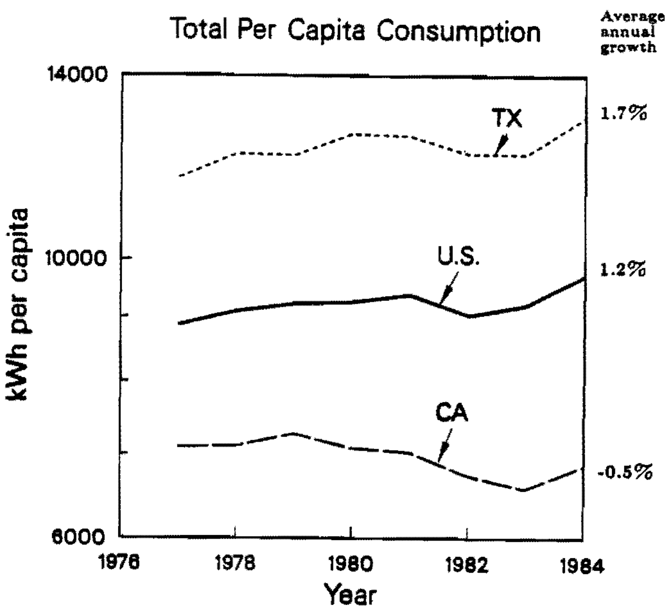

Figure 1. Total electricity consumption by all customers for CA, TX, and U.S. Annual electricity consumption is normalized to per-capita use in the same year. In the seven years 1977-1984, California population grew by 2.0%/year, Texas by 2.8%/year, and the U.S. by 1.0%/year. The y-axis is logarithmic.

Texas is now following in California's footsteps, advancing a range of conservation and load management initiatives. The Texas Public Utilities Commission is planning to "construct" an 800 MW "conservation power plant" for the city of Austin by deploying a package of residential retrofits that will cost several times less than new generation capacity. Texas is also pursuing load management strategies, such as thermal storage for cooling commercial buildings as a means of avoiding the construction of new plants. One-third of new commercial floor space in Dallas now employs thermal storage, which shifts 20-25% of new cooling load to off-peak times (5).

As a result of conservation efforts, the overzealous projections of demand growth and the accompanying construction plans of the early 1970s have not become a reality. From the data presented here we cannot tell precisely how much of the difference between California and Texas is due to regulation, but it is clear that California has demonstrated more of a will to conserve at both the government and private levels.

REFERENCES AND NOTES

1. The work described in this report was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Services Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
2. Readers interested in receiving copies of the full report with data tables and figures may contact the authors at Building 90/3125, Lawrence Berkeley Laboratory, Berkeley CA, 94720. Ask for LBL-22932.
3. A 1000-MWe power plant sells roughly 5 BkWh per year.
4. Sources for Tables 1 & 2: Electricity-Electric Power Annual 1984, Energy Information Administration (EIA),U.S. Department of Energy EIA-03048, Table 45, pages 127-31, September 1985. Energy Prices--State Energy Price and Expenditure Report 1970-1982, EIA-0376, pages 17, 67, and 457. Population, Industrial Value-added and Income--1986 Statistical Abstract of the United States, Table 12, page 12; Table 1336, page 750; and Table 735, page 440 respectively, U.S. Depasrtment of Commerce. (1977 income, 1978 Statistical Abstract, Table 725, page 449). (Income data are used as a proxy for GSP). Commercial floor space--1985 NBECS Survey DOE/EIA-0246(83) (data by Census Region) and DOE/EIA-0453 Model Documentation: Commercial Sector Energy Model, August 1984.
5. Personal communication, Leo Stambaugh, Texas Utilities, January 1987.

THE TECHNOLOGICAL FEASIBILITY OF STRATEGIC DEFENSE by Dietrich Schroeer, Department of Physics and Astronomy,University of North Carolina at Chapel Hill

Introduction

The current debate about strategic defense is ultimately political. None the less, there are underlying questions about the technological feasibility of such a defense. The first question is whether specific weapons might be able to produce sufficient energy to destroy offensive strategic weapons. The second question is how effective the weapons might be as part of an operational defensive system.

Physicists may not be particularly competent to judge the capabilities of defense systems. But they can analyze the capabilities of weapons *per se*, particularly with respect to the minimum technical requirements that must be met by the weapons if they are to be incorporated into the defensive systems.

This note will review the capabilities required for several weapons that might be useful as components of certain specific defensive systems. Based on past rates of technological improvements, current weapons capabilities will be projected into the future, to estimate when sufficiently capable weapons might be available for deployment. Building strategic defense systems will be more difficult than developing individual weapons. The availability of sufficiently capable weapons therefore is a minimum but not sufficient prerequisite for effective strategic defense. The date for the projected availability of prototypes of specific defensive weapons will therefore be a minimum estimate for the availability of adequate strategic defenses.

Weapons Requirements

The requirements for defensive weapons depend on the goal of the strategic defense system of which they are to be a part. Table 1 lists a set of possible goals for strategic defenses, together with some of the weapons that might have to be a part of each defense. The revolutionary nature of the strategic defenses proposed in President Reagan's "Star Wars" speech is most visibly symbolized by directed-energy weapons (DEW). Therefore, Table 2 lists one representative DEW system for each of these goals, and outlines the technical requirements it might have to meet (1,2).

Table 1. Possible objectives of strategic defenses.

Strategic Objective	Defensive Strategy	Weapons	DEW Deployment Date
Deterrence by threat of retaliation	Preferential defense, to preserve retaliatory capability	Terminal ground-based lasers or charged-particle beams or ground-based ABMs	1995
Deterrence by denial	Terminal defense plus 25% area defense, to disrupt first strike	Some space-based DEW boost-phase plus two-layer ABMs	2000
Transition to defensive regime	90% effective area defense, damage limitation	DEW boost, DEW and KEW mid-course, two-layer ABMs	2000-2030

Table 2. Requirements for several laser weapons symbolic of different defensive objectives.

	Terminal defense	Boost-phase defense	Midcourse defense
Laser type	DF-chemical	HF-chemical	free e^-
Wave length	3.8×10^{-6}m	2.7×10^{-6}m	0.5×10^{-6}m
Laser location	ground	space	ground
Target distance	10 km	3000 km	75,000 km
Mirr diameter	4 m	10 m	50/26/2m
Laser output	2 MW	20 MW	1000 MW
Kill energy	150 kJ/cm^2	20 kJ/cm^2	50 kJ/cm^2
Kill time at max range	0.16 sec	8 sec	0.66 sec

(i) In many ways, short-range ABMs are the logical weapons for a terminal defense system that is to protect ICBM silos against attack in order to preserve the retaliatory capability necessary for maintaining deterrence by the threat of mutual assured destruction. However, a study of DE weapons indicates that a 2-MW DF laser with a 4-m focusing mirror might be useful for such a terminal defense.

(ii) A space-based laser system for boost-phase intercept might be usable as part of a defensive system to maintain a posture of deterrence by denial, by denying the opponent any military advantage through a first strike. A space-based 20-MW HF laser with a 10-m diameter mirror might be useful for such a defense.

(iii) A 1000-MW ground-based free-electron laser (fel) with a 50-m focusing mirror and a 25-m geosynchronous reflector mirror might be useful in an extensive midcourse strategic defense that is designed to limit the damage to populations from a small-scale nuclear attack.

The problems faced by these DE weapons are symbolic of the technical difficulties of developing effective components for these different defensive strategies. Other weapons, such as particle beams, x-ray lasers, and electro-magnetic railguns, are not likely to be much easier to develop, although they may have unique attractive features. But similar evaluations could be made of the requirements imposed on these alternative weapons.

Weapons Availabilities

Given that these DE weapons must satisfy the performance parameters listed in Table 2, when might they be available for incorporation into defensive systems? It is risky to extrapolate past technological developments into the future. But it is also risky to have no notion of when some technological goal might be achieved. Therefore it makes sense to perform such extrapolations, with the understanding that they are only estimates to which other projections can be compared. Table 3 displays projections for some DE weapons.

Table 3. Estimates of times when the feasibility of various strategic-defense weapons might be established, and when they might be available for deployment.

Defense	Weapon	Range	Parameter	Feasibility	Prototype
Terminal	DF laser	10 km	2 MW laser	1987	1992
			4 m mirror	1990	1995
Terminal	e^- beam	10 km	10 kA at 500 MeV	2006	2011
Boost-phase	HF laser	3000 km	20 MW laser	1995	2000
			10 m mirror	1996	2001
Mid-course	fel laser	75,000 km	1000 MW laser	2012	2017
			50 m mirror	2027	2032
Mid-course	H^0 beam	3000 km	5A at 500 MeV	2001	2006

The current maximum power output of HF lasers is 2 MW, as projected for the *Alpha* laser for 1987. Historically the maximum power output of the best lasers at any moment has doubled roughly every 2.5 years (3). Hence the 20-MW power output necessary for space-based boost-phase defense might be demonstrated in 1995. Historically, within this envelope of maximum power output, different types of lasers have undergone more rapid development rates, sometimes with a power-doubling period as short as 1.5 years. However, once this maximum power envelope has been reached, the development times then have fallen to 2.5 years. The current maximum power output of free-electron lasers is 5 kW. At a growth rate of 1.5 years, fels could catch up with HF lasers by 2000. With a doubling period of 2.5 years thereafter, they might develop a power output of 1000 MW by 2012.

Extrapolations of mirror capabilities are more uncertain, because there has been little pressure in the past decades to develop larger mirrors, particularly mirrors with the heat-resistant and active-optics properties required for weapon mirrors. But an estimate of 3 years for each doubling of mirror area seems reasonable, with a consequent doubling time of 6 years for the mirror diameter. Table 3 shows the resulting dates of potential proven feasibility for the various mirrors. The long time period for the development of a ground-based mirror for the fel midcourse weapon is not only due to the fact that the requisite mirror is so large, but that it involves the extrapolation of the relatively unknown technology of active mirror optics.

Combining the laser and mirror requirements in Table 3 gives the most likely date for the proof of feasibility of the various weapons. A period of 5 to 8 years typically elapses between the demonstration of the technological feasibility of a device and the completion of a prototype. Thus, the beginning of production and deployment of a weapon cannot begin until 5 to 8 years after the technical feasibility is demonstrated. Table 3 shows estimates for these earliest dates of initial deployment. Some of these estimates may be compared to dates estimated by the former U.S. Secretary of Defense Harold Brown (4).

It is important to remember that such estimates cannot be used to decide when a functioning system of affordable cost might be available. And, since such estimates are based on past rates of technological development, they are uncertain, particularly when extrapolations from the past have to stretch far into the future. None the less, such extrapolations into the future of technological developments will provide benchmarks against which to compare present promises of future weapon capabilities. Hence they can help delimit political expectations, and constrain hopes to conform to some possible realities.

Conclusions

The words "earliest possible" are important modifiers in statements of possible initial dates of deployment of strategic weapons. The feasibility of weapons is only a minimum requirement, since the weapons must then be incorporated into defensive systems. It is widely agreed that building the weapons systems will be much harder than building the weapons (5). Hence weapons systems will come much later than the weapons.

These extrapolations are not intended to be the exact truth. There have been past examples where crash programs have produced short cuts in development--the Manhattan District's development of the first nuclear weapons comes to mind. But there are also past examples where crash programs have been unable to produce weapons systems on an accelerated time scale; in some cases weapon systems produced by a crash program were ultimately judged of too low capability to be interesting--as for example the ABM system of the early 1970s.

Those who argue that strategic defenses will be ready for deployment in the next decade either are proposing a terminal defense, or they ought to demonstrate why they believe that the estimates presented here are pessimistic. On the other hand, those who argue that strategic defenses will never work, either are discussing a perfect population defense, or they ought to demonstrate why the estimates presented here are optimistic.

REFERENCES AND NOTES

1. For details of these calculations see D. Schroeer, *Directed Energy Weapons and Strategic Defense; A Primer*, Adelphi Paper (International Institute for Strategic Studies, London, to be published in 1987).
2. These values may be compared to the values generally cited, e.g. in A. Carter, *Directed Energy Missile Defense in Space (A Background Paper)*, (Office of Technology Assessment, Washington, D.C. 1984).
3. The growth of the power output of lasers is discussed for example by J.F. Coneybear, "The Use of Lasers for the Transmission of Power," *Progress in Astronautics and Aeronautics* 61 (1978), pp. 279-310. For example, in 1970 a 20-kW chemical laser was available, while a 2-MW HF laser is supposed to become operational after 1987. That would represent 6.6 doubling periods over 17 years, or a doubling time of about 2.5 years.
4. H.Brown,"Is SDI Technically Feasible?" *Foreign Affairs* **64**, No. 3 (1986), pp. 435-454.
5. R.R. Ropelewski, "Battle Management,C^3 I Network Challenges Resources of SDI Office, " *Aviation Week & Space Technology* **123**, No. 3 (July 15, 1985), pp.19-21.

SDI SOFTWARE: THE TELEPHONE SYSTEM ANALOGY. PART I: THE SOFTWARE WILL BE RELIABLE, by Sol Buchsbaum, Executive Vice President for Customer Systems, AT&T Bell Labs

[Editor's Note: We present pro and con on the SDI software debate. Part I is excerpted from Sol Buchsbaum's tesitmony to the Senate Armed Services Committee's hearings on the SDI, 3 December 1985. For more information on the presentations of Buchsbaum and others at those hearings, see *Physics Today*, January 1986, pp. 79-80. In addition to his position with Bell Labs, Buchsbaum has served on the SDI advisory committee, chaired the White House Science Council, and chaired the Defense Science Board's task force on command and control systems management. Part II is a response to Buchsbaum's testimony by Karl Dahlke of the Bell Labs technical staff and participated in by 16 other cosigners who are also Bell Lab technical staff members. Of course, neither article necessarily reflects the views of Bell Labs.]

Let me say at the outset that I recognize that the strategic defense initiative faces enormous challenges and problems which I do not minimize. However, a vision of the world in which the two superpowers have agreed to constrain their respective offensive nuclear forces to levels much lower than today's and, at the same time, have also agreed to protect themselves and their allies against nuclear attack with defensive systems--a protective shield--of reasonable effectiveness is an attractive one. Surely, that would be a more stable world than the one in which we live today.

I want to address particularly the challenges of integrating the various elements into a complete system whose parts work coherently to accomplish the SDI mission. A key function that must be considered from the very beginning in coming up with this integrated system is battle management and its associated command, control and communications, BM/C^3 for short. Here I want to go into some detail because recently BM/C^3 has been raised as the area in which we face the greatest--some say impossible--challenges.

The battle management/C3 function is basically a problem of information movement and management--involving all SDI elements as well as key human decision makers. The problem is not easy because of the vast quantities of information that must be obtained, processed, and synthesized throughout a large geographically distributed system, and done so quickly. Such a system, it has been estimated, would require tens of millions of lines of software. The issue of software complexity is compounded by the associated needs to test, simulate, modify, and evolve the Battle Management System.

Some critics have specifically questioned if it is possible to generate great quantities of error-free software for the system, and to ensure that it is, indeed, error-free software. This is the wrong question. Designers of large real-time systems--systems that depend on complex software and hard-ware--know that it is impossible to generate great quantities of error-free software. They also know that major problems in field use of software need not be associated with program bugs. Software is always part of a larger system that includes hardware, communications, data procedures, and people.

The right question, as well as the key issue, is the broader one of whether the total BM/C^3 system can be designed to be robust and resilient in a changing and error-prone environment. The key, then, is not whether the software contains errors, but how the whole system compensates for such errors as well as for possible subsystem failures. The BM/C^3 system must operate continuously and reliably despite any errors or failures. Parts of the system must cover for each other to limit the effect of such problems--and they must do so quickly, typically in milliseconds or seconds.

Can such a large, robust, and resilient system be designed--and not only designed, but built, tested, deployed, operated, and further evolved and improved? I believe the answer is yes. I seem confident of this answer because most, if not all, of the essential attributes of the BM/C^3 system have, I believe, been demonstrated in comparable terrestrial systems.

The system most applicable to the issue at hand is the U.S. Public Telecommunications Network, with which I am quite familiar. The network has attributes that are intrinsic to the BM/C^3 system as well. These include the capabilities for continuous, reliable operation; for fault tolerance and overload control; for evolution in response to changing demands, functions, and advancing technology; for human control over key operations if and as required; for compatibility and interoperability among all systems; and for continuous testing, diagnosis, and maintenance--much of it by remote means. I might say that this network today needs for its operation well over 40 million lines of software. In other words, the telecommunications network has high reliability, availability, maintainability, and adaptability. And the network achieves these capabilities largely because it is a distributed system that uses redundancies and that uses well-specified, well-controlled interfaces in the coupling together of all component systems.

Now, let's imagine for a moment that the switching machines in the network are SDI battle stations; and that everything connected to the network, feeding information into it and requesting action-phones, data terminals, private branch exchanges and so forth-corresponds to SDI sensors. Let's also imagine that the network signaling system that interconnects all switches is the nerve system. By the way, these switches, these battle stations, contain large computers. A typical switching system today operates with over 2 million lines of code. The total network needs over 40 million lines of code. Some network battle stations, each with its own brain, are connected to others directly and some indirectly, but all are interconnected in a hierarchy. And these battle stations can communicate with one another, but not on an equal basis. Some communications take priority over others in a prescribed way. Each battle station has a preassigned task--say, to attack and kill a predetermined set of targets. That task must be accomplished no matter what the workload presented to the battle station is. So, over load control is an important attribute. We know how to do that. The total network is designed to accomplish its task no matter what happens. When there is a failure in some part of the network, some other part of the network takes over that task. So it should be in an SDI system.

In telecommunications network, there are many "battle stations" or switches--20,000 local and nearly 1000 toll switches. And roughly 105 million "sensors" or telephones are connected to the network by 85 million access lines. Some network elements are enormously complex, highly reliable computers. For example, the 4 ESSth switching system, today's lagest, can process and route over 700,000 calls per hour, and uses a program of about 1.3 million lines of code.

With this comparison between the telecommunications network and SDI in mind, let's examine the lessons we learned from helping to develop, test, deploy and operate the network. They suggest that there are three keys to achieving high reliability, availability, maintainability, and adaptability.

The first is the use of distributed architectures both for the entire network and for major systems within the network. This approach compartmentalizes crucial functions in modules throughout the country as well as within individual systems. And the approach also helps minimize software complexity, a constant concern in large-system design. Even though the total network requires over 40 million lines of software, for example, each component system requires no more than two million lines. The second key is the use of redundancy, again both in the entire netowrk and in the component systems. And the third key is the coupling together, the integration, of all the componenet systems by means of well-specified, well-controlled interfaces.

I conclude this short summary by pointing out that these lessons learned are directly applicable to the major SDI challenges of battle management and associated command, control, and communications.

PART II: THE SOFTWARE WILL NOT BE RELIABLE, by Karl Dahlke, Technical Assistant for software architecture in air traffic communications, AT&T Bell Labs, Naperville, IL, and 16 co-signers (1).

On December 3, 1985, Sol Buchsbaum, executive vice president of AT&T Bell Laboratories, testified before the Senate Subcommittee on Strategic and Theater Nuclear Forces. In his statement, Dr. Buchsbaum compared the Strategic Defense Initiative (SDI) to the United States telephone network, in order to demonstrate the technical viability of SDI. We feel this comparison is irreparably flawed, and that SDI is a dangerous and destabilizing program. For this reason, we must respond to Dr. Buchsbaum's statement.

Although we are employed by AT&T, and many of us design the very telecommunications systems Dr. Buchsbaum references, we do not represent AT&T or any other organization. We make this statement as concerned citizens - well informed citizens on this issue.

Paraphrasing, Dr. Buchsbaum's testimony states that, since the phone system is extremely reliable, and it is analogous to SDI, SDI may thus be technically feasible. He then spends several pages explaining how the phone system attains its impressive reliability, without questioning whether this reliability is adequate, or whether the two systems are, in fact, analogous.

The comparison between the phone system and SDI is fallacious for the following four reasons:

1. SDI operates in Space

System availability depends critically on two parameters, the mean time between failures and the mean time to repair. The impressive availability of the phone system (3 minutes downtime per year for telephone switches) is due, in part, to established procedures that ensure quick repairs. Quoting Dr. Buchsbaum, "Once isolated, faults can easily be fixed by replacing or repairing the small part -- for instance, an insertable circuit pack." Most phone switches are monitored 24 hours a day, and spare parts are stored close by. Whenever a component fails, a technician can make repairs immediately. Without this capability, sequential errors overlap in time, and system reliability plummets.

Unlike the phone system, SDI components cannot be replaced or repaired quickly. At best, mean time to repair is measured in weeks. At worst, replacing critical space-based components might take years, as recent rocket failures illustrate. Sequential failures could easily combine to compromise entire subsystems.

While we cannot rule out the possibility of a maintainable space-based defense shield, Dr. Buchsbaum's arguments leave us unconvinced.

2. A strategic defense faces countermeasures

Widespread fraud illustrates the vulnerability of our nation's phone system. Amateur hackers and professional criminals circumvent the ever-tightening defenses of the telecommunications network. An entire crime industry in fraudulent long distance calling persists in New York City and elsewhere. Fortunately, these organizations do not attack the physical or operational integrity of the phone system directly. A functional, reliable telecommunications network benefits customer and criminal alike. Unlike the phone system, a strategic defense faces an intelligent, organized adversary who actively opposes its underlying function.

Even if we assume the Soviets will not attack the system directly, credible countermeasures abound. Soviet engineers will obtain the criteria used to distinguish warheads from decoys and will have decades to quietly construct warheads that resemble decoys and vice versa. Even without benefit of the system's blueprints, missiles can be equipped with such features as fast-burn rockets, heat-resistant surfaces, electromagnets, or mirrors, depending on the system specifications for boost-phase intercept. A handful of relatively inexpensive countermeasures can circumvent the most elaborate multi-layer defense.

The telecommunications network, the Apollo space program, and other impressive technological accomplishments were never threatened by an intelligent enemy. They are simply not comparable to SDI.

3. SDI must work the first time

Quoting Dr. Buchsbaum, "the network gracefully evolves each and every day, with new equipment being installed and with older equipment being reconfigured or removed." Unlike Dr. Buchsbaum, we have worked with the million-line software modules that control the telephone network. We have been in the test labs, we have run the simulations, and we have watched our equipment perform in the field. Engineers, operators, and affected customers agree -- modifications to the phone system are anything but graceful.

Despite rigorous tests and simulations, the first time new equipment is incorporated into the telephone network, it rarely performs reliably. Fortunately, it doesn't have to. A group of irate customers doesn't compare to the catastrophic results of a strategic defense failure.

Adding new equipment is just the tip of the iceberg; even the simplest software upgrade introduces serious errors. Despite our best efforts, the software that controls the telephone network has approximately one error for every thousand lines of code when it is initially incorporated into the phone system. Extensive testing and simulation cannot discover these errors. If SDI contains ten million lines of software (a credible estimate), and its quality is comparable to the telephone network, we can expect ten thousand errors embedded in its software when the Soviets attack. It only takes a few disastrous software errors (one per layer) to cripple any multi-layer SDI implementation.

Throughout this discussion, we have been unrealistically optimistic, citing failures that inevitably accompany relatively simple modifications to a functioning network. Errors resulting from overall system design or ambiguous specifications are not even addressed. Suppose the entire phone system had to perform reliably the first time it was used. If AT&T had spent the last century testing, inspecting, verifying, and simulating, could the phone system perform reliably when millions of customers began using it?

4. Space-based communication channels must remain secure

As described above, each 100,000 line software package typically contains hundreds of errors when it is first introduced into the phone system. As each error is discovered and corrected, automated procedures disseminate the corresponding software modification to each affected site. When security is required, it is technically and economically feasible to disseminate software updates in a secure manner. Cleared persons can physically carry software changes on tape or disk to each affected telephone switch.

Unlike the telephone system, software updates cannot be physically delivered to hundreds of space-based components. Instead, they must be transmitted from a few designated locations using an encrypted signal. While this method will work for awhile -- perhaps several decades -- nothing remains secure forever. Once an enemy agent steals or buys the encryption key and gains access to a transmission site, each passing satellite can be completely reprogrammed.

Intersatellite communications and network reconfiguration directives must be encrypted as well. This prevents an enemy from launching a countersatellite that says, "I am part of the network, and I am handling these missiles." All these communication channels must, somehow, remain secure indefinitely.

While it is difficult to estimate the probability of a software security breech, or the amount of counterprogramming that can actually be accomplished, SDI communications are certainly not comparable to the telephone system. Software maintenance, network reconfiguration, and battle management all require permanently secure satellite communication channels that have no counterpart in today's telephone system.

Conclusion

Although we do not require a perfect design, we do feel that any implementation must be trustworthy. The importance of reliability should not be underestimated. A strategic defense will never reduce our dependence on nuclear weaponry if it cannot be trusted to work the first time, despite Soviet countermeasures. Would you, personally, trust such a system? Would SDI, in and of itself, give you the confidence to support a bill drastically reducing the number of nuclear weapons in our arsenal? We have worked on some of the most reliable systems in the world, and based on our experience, we would not trust any SDI implementation.

We feel that SDI is unworkable and destabilizing, and we urge Congress to reject any budget that allocates a substantial portion of the nation's limited research funds to SDI. Furthermore, we encourage Congress to work toward a comprehensive test ban and a stronger, unambiguous, verifiable ABM treaty.

The nuclear arms race is a pressing political and social problem that SDI cannot solve.

REFERENCES AND NOTES

1. The co-signers, and their fields as members of the Bell Labs technical staff, are Krista F. Anderson (software developer, cellular telephony), John D. Bagley Ph.D.(supervisor, AT&T computer center), Andrew S. Berman (instructor, telephony and programming languages), E. T. D. Calhoun Ph.D.(software architect, telephone switching systems), Marilyn O. Cole (software development tools and resources), Daniel L. Dvorak (network design, AT&T computer center), Dorothy E. Harris Ph.D. (software artchitect, 5ESS Switch), Paul Hunter (systems engineer, telephone switching systems), Jesse S. Kartus (networking and protocols, government applications), Lewis Mammel, Jr. Ph.D.(distributed data bases in telephony), Richard Oppenheim Ph.D. (simulators and expert systems), K.R. Perlow (UNIX and distributed operating systems), Armin Roeseler (modeling and performance, AT&T computer center), Jesse F. Shumway (software testing, telephone switches), Daniel C. Starr (systems architect, 5ESS Switch), Charles Varvaro (systems architect, air traffic communications).

ORBITAL DEBRIS: AN INEXPENSIVE COUNTERMEASURE TO SPACE BASED WEAPONS SYSTEMS by John R. Michener, 177 Moore St., Princeton, NJ 08540

Abstract

The deployment of debris in equatorial orbits would be an efficient and cost-effective countermeasure to the establishment of orbital weapons platforms. The presence of orbital debris would force the building of orbital platforms to build and maintain massive shielding to protect the platforms. The cost ratio between attacking a system of orbital structures with a debris belt and defending the structures from the belt would be highly favorable to the building of the belt. The creation of such a belt would severely limit the use of the affected regions of space for any use whatsoever.

Introduction

While there are a wide variety of methods that could be used to attack structures in space, this paper reports upon a method that can render regions of space of military importance unusable, is relatively inexpensive, long lived, and immune to countermeasures: The deployment of an equatorial debris belt at the appropriate altitudes.

For an orbital debris belt to be stable and long lived, collisions between particles within the belt must occur at very low velocities. The orbital inclination of the particles or fragments after collision approximate the mass average of the orbital inclinations before collision, reducing the velocity dispersion of its particles and stabilizing the belt (1).

The collision velocity for orbital platforms with equatorial debris in a low earth orbit as a function of orbital inclination angle is given by $v_{coll}=7.9[2(1-\cos\theta)]^{1/2}$. Typical collision velocities range from 8 to 11 km/s (orbital inclinations of 60° to 90°) with corresponding collision energy densities of 30-60 KJ/gm (TNT has an energy yield of 4 KJ/gm).

Perhaps the orbital systems most vulnerable to impact would be solar power panels. The semiconductor receptor and window material are very brittle (fracture energies < $10 J/m^2$) rendering them vulnerable to damage by very small particles. Heat radiators, such as are used with radioisotope or nuclear reactor power sources, would be somewhat less vulnerable (assuming that the individual tubes were designed to isolate themselves after a tube puncture), but they would still be vulnerable to tube punctures by quite small debris particles: A 50 micron tungsten particle could puncture a tube with a wall thickness of ~.7 mm.

Fuel would be needed for maneuvering, orientation control, and power production in the orbital platform. If impact damage allowed oxidizer to mix with fuel, the orbital structure could be destroyed. Damage to oxidizer storage would prove a considerable corrosive threat to all orbital components. Damage to the optical surface resulting in a high absorptivity would result in the local absorption of beam energy and the damage and destruction of the adjacent optical surface and, perhaps, destruction of the mirror itself - if it were ever used. Low mass particles could easily damage electronic or imaging components, circuit connectors, and circuit boards. Impact with objects with masses larger than one kilogram could threaten the mechanical integrity of the orbital platform. The energy yields of such impacts, equivalent to approximately 10 times their mass of TNT, could demolish and disrupt orbital platforms and their substructures.

Shielding of Orbital Structures

Spacecraft and orbital structures are constructed for minimum mass in order to minimize launching costs. As such they are typically composed of low-mass trusses and thin walled structures, which are highly vulnerable to damage by low-mass debris particles. The interaction of such structures with debris at typical interaction velocities of 10 km/s has been studied for the design of manned orbital space missions (2,3). These studies show that, while a very small object could do enormous damage to a structure or massive object if it strikes it, such damage could be avoided by the proper use of multiple wall shielding (2,3,4). Aluminum multiwall shielding designed to stop debris at 10 km/s needs a cross-sectional density ~ .75 times that of the object that it is designed to stop (2,4).

Atmospheric drag rapidly removes fractional gram objects at altitudes of less than 1000 km, preventing the establishment of a long lived debris belt of very low-mass objects at low altitudes (5). Above 2000 km altitude even objects in the sub-microgram mass range have long lifetimes. Debris in the form of heavy metal needles could have cross-sectional densities considerably greater than the cross-sectional densities of the heavily shielded orbital platforms, allowing their deployment at any altitude for which platforms could be placed in stable orbit.

Attack on Orbital Structures

Orbital platforms could be attacked by placing a relatively low density of objects into equatorial orbit since the platforms would cross the equatorial debris belt ~ 10,000 times per year. Consider the case of an orbital platform with a cross-secitonal area of 200 m^2 (diffraction-limited optical system with a 10 m diameter and a mass of 200 tons (6)), of which 100 m^2 is critical (if hit in this area by a massive object that was not stopped by shielding, the platform would be destroyed) interacting with an orbital debris belt with one object per 10^6 m^2. During a year the platform would have a ~ 60% chance of being struck by at least one object in the critical area and an ~ 85% chance of being struck somewhere by at least one object. A belt with this density between 250 km and 1000 km altitude would require ~ 30 X 10^6 objects (twice as many objects would be required to establish the belt between 250 and 1600 km). A debris belt could be deployed by rockets (probably solid fueled) that could be detonated to provide a population of rocket fragments in addition to the metal shot and fuel burn residue that would constitute the low mass debris. Since the payload of a solid fuel motor is ~ 25% of its empty mass (7), most of the debris mass would be booster fragments.

Two hundred platforms (8) with an effective area of 200 m^2 each would have a combined shielding area of 40,000 m^2. The mass of the optical components of a laser platform system probably would be in excess of 40 ktons, at a cost of ~ $23,000 per kg (6) (not including costs to raise them to orbit). If the builder of the belt placed 40 ktons of dense objects (at a cost of from $10 to $100 per kg, depending upon material and fabrication expenses) into orbit between 250 and 100 km with an orbital density of 1 per 10^6 m^2, the average mass per projectile would be 13 kg. If the projectiles were deployed as rods and spheres, average shot cross-sectional densities of 100 - 150 gm/cm^2 could be expected, requiring shielding masses on the order of 1 ton/m^2 to protect the platforms from the heavy metal shot alone. This would require the deployment of at least 40 ktons of shielding (9). Since deployment over such a wide range of altitudes would require an increase in the number of platforms, the mass exchange ratio for the shielding would be unfavorable. In addition to the heavy metal shot, 320 ktons of booster motor fragments would be available to the builder of the debris belt. This would allow the builder of the belt to establish a significant threat that a platform could be struck by an object significantly more massive than 13 kg, requiring the deployment of even more massive shields. It also would allow the establishment of a much higher density belt of much less massive objects.

In general massive objects would strike platforms a considerable distance from their center of mass, imparting a considerable rotational impulse to the platform. This would result in the platform tumbling, exposing its unshielded side to orbital debris. Since impact with even very low mass debris on unshielded portions of the platforms would be very destructive, it would be necessary for the platform to have active stabilization to allow it to reorient itself rapidly, increasing the mass and complexity of the platform.

In addition to the mass of the optical systems, orbital platforms would require additional mass for pointing, shielding, beam generation, fuel, and control. A minimal mass of 400 tons per orbital unit including optics, beam generation, pointing, and control would not be unreasonable. Such a mass would imply a total orbital mass of orbital platforms of at least 80,000 tons (plus the necessary mass of shielding). If the laser beams were generated by ground-based installations the beam generation mas could be removed from the orbital stations. This would be somewhat countered by the requirements for larger optics to correct for atmospheric and geometrical effects, which would raise the optical mass. An increase in the number of missiles to be attacked would require a corresponding increase in the number of orbital platforms and orbital mass needed.

The mass and cost exchange ratio may similarly calculated for orbital platforms utilizing kinetic energy weapons. Due to the flight time requirements of such weapons, platforms utilizing them will need to be placed into low orbital space and will have to be more closely spaced than would be required for laser platforms, requiring a large number of platforms. The resulting high density of platforms would be very vulnerable to heavy debris objects as well as secondary debris resulting from the destruction of platforms by primary debris objects.

While not as immediately destructive as massive objects to heavily shielded structures, low mass objects would pose a considerable threat due to their gradual attrition of all orbital objects. When a particle collides with a thick plate, many times its own mass is ejected from the plate (10), posing a considerable threat to sensor and communications equipment.

The debris populations discussed above would make the affected region of space essentially unusable for the indefinite future. The debris population would gradually loose its perpendicular momentum and settle to the equator(5), where it would form an extended ring. The debris and booster fragments used in the construction of a debris belt would be relatively inexpensive, expendable, and very durable, allowing the use of unreliable launch vehicles.

Conclusion

Debris deliberately placed in equatorial orbit would be an inexpensive countermeasure to space based weapons platforms, forcing the deployment and maintenance of massive shields. The total shielding mass to protect orbital platforms against massive objects would exceed the comparable orbital debris mass. The cost to attack a system of orbital structures with a debris belt would be a small fraction of the cost of the orbital systems. Such a belt would seriously hinder the manned use or exploration of space (11)

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6. George Field and David Spergel, "Cost of Space-Based Laser Ballistic Missile Defense," *Science* **231**, 1986, pp. 1387-1393.
7. Cochran, Gorman, and Dumoulin, *The Space Handbook, 12th revision*, Air University Press, Maxwell AFB, 1985.
8. A minimal number with the satellites all at relatively low altitudes(6).
9. The shielding mass that would be needed is proportional to the cross-sectional density of the debris that it is designed to stop. For compact objects, the mass of a debris particle would be proportional to its $(size)^3$ and hence to its cross-sectional density.
10. The mass exchange ratio is ~ 130 for soft Al and many thousands for glass and semiconductors.
11. A more complete version of this paper is available from the author. Send a stamped, addressed envelope.

A RETROGRADE SWARM MODEL by Charles H. Powell, 509 Riverview Drive, Bristol, TN 37620

This report describes the results of work with a mathematical model, which is used to estimate how often an orbiting satellite can expect to be hit by pellets from a swarm in a retrograde orbit. Because of the energy advantage of being launched with the assistance of the earth's rotation, a large majority of satellites have an west-east prograde orbit. Concerns have been voiced about the hazards created by the man-made debris in orbit around the earth (1), most of which is prograde. However, a given amount of debris in a retrograde orbit is clearly more dangerous than the same amount of debris in a prograde orbit. This is because the higher relative velocities mean higher impact energies and high frequencies of encounter. This raises the question of military potential, which does not seem to have been noticed in the public studies on this subject (2).

Provided the expected frequencies of hits are high enough, a nation might find it advantageous to release a retrograde swarm as a hazard to a threatening satellite or system of satellites. Although there are quicker and more direct ways of destroying satellites, some military advantages of such swarms can be enumerated. They would be technically simple and thus relatively inexpensive. Potentially they would be much less expensive than their targets. They would have a sustained effect against their targets and any replacements in similar orbits. Their deployment could be quite remote from their target and thus less susceptible to active counter-measures. Their effect would not require the active participation of their instigator and could not be clearly distinguished from the effect of the background hazard. They would thus be less confrontational than more direct methods. Their legality under international law appears to be unclear. Retrograde swarms would have the disadvantage of denying to all, including their instigator, a certain volume of the orbital phase space. The instigator could try to minimize this disadvantage to himself by carefully controlling the parameters of the release and keeping them secret. The feasibility of observing a swarm after its release is not clear.

Conversely the potential use of retrograde swarms, if effective, would cause a number of difficulties for those wishing to maintain long term military operations in near-earth space. Using a large variety of orbits that are of high radius and eccentricity could reduce the risk at the cost of greatly increasing design and operational complexity. Using heavy armor, multiple redundancy, and repair capacity could reduce the risk, at similar cost. Despite such steps, satellite reliability could still be in doubt.

Thus it would appear that a militarization of space in which one party began to predominate, could have as a major component the widespread use of retrograde swarms. This could endanger all uses of space including the strategically stabilizing functions of intelligence and communications, not to mention scientific study. It would seem to be in the interest of all concerned to conclude a comprehensive treaty to regulate the military use of space which would include a ban on retrograde swarms.

Of course all this is speculative, unless the potential effectiveness of retrograde swarms is established. That is the goal of the model (3). First we assume equally inclined, elliptical orbits for the target satellite and the center of the swarm. We then assume, for the swarm pellets, a normal distribution centered around the swarm orbit in the radial dimension and in the angular dimension perpendicular to the swarm orbit. From this, we derive a local expected frequency of being hit. This is then integrated over the orbit of the target. Because of the relatively rapid change, in both the orientation of each orbit in its plane and in the points where the orbital planes cross the equator, we average over all possible values for these parameters. The resulting expectation is complicated and numerically unwieldy. But we subject it to analysis obtaining bounding estimates, which are decoupled into the product of five factors. The resulting inequalities are

$$F_c F_s F_{min} F_r F_a \leq H \leq F_c F_s F_{max} F_r F_a$$

where H is the expected frequency of hits. The factors have a simple dependance upon the parameters and are numerically amenable.

The characteristic factor, F_c, is given by

$$F_c = A_t N_s \mu / 2^{3/2} \pi^2 b^{1/2} r_e^{7/2}$$

where A_t is the target's area, N_s is the number of pellets in the swarm, r_e is the earth's radius, and $b = 4 \times 10^{14}$ m^3/s^2. This factor has the dimensions of hits per time and all the other factors are dimensionless. If we take for example, $A_t = 100$ m^2 and $N_s = 10^9$, we calculate

$$F_c = 1.1 \times 10^{-7} \text{ hits/s} = 3.5 \text{ hits/year}$$

The model is linear in N_s and A_t, so that when these values differ the result will differ proportionally.

The scaling factor given by

$$F_s = (r_e/a_t)^{7/2}$$

is the only factor dependent upon the scale of the orbit and is a power of the ratio of the semi-major axis of the target orbit, a_t, divided by the earth's radius r_e.

The adjustment factors $\{F_{min}, F_{max}\}$ are given respectively by

$$F_{min} = [2R^3(\frac{1}{1 - e_t} - \frac{1}{2R_{max}})]^{-1/2}$$

and

$$F_{max} = [2R^3(\frac{1}{1 + e_t} - \frac{1}{2R_{min}})]^{-1/2}$$

where $R_{max} = \max(R,1)$ and $R_{min} = \min(R,1)$ and R is the ratio of the semi-major axis of the swarm and target orbits and where e_t is the target eccentricity. A lower bound is given when F_{min} is used as a factor. An upper bound is obtained when F_{max} is used as a factor.

The radial distribution factor F_r is given by

$$F_r = \pi^{-2} S^{-1} \int_0^{\pi} dx \int_0^{\pi} dy \exp[-(R_x - R_y)^2/S^2]$$

where

$$R_x = R(1 - e_t^2)/(1 + e_t \cos x)$$

and

$$R_y = R(1 - e_s^2)/(1 + e_s \cos y)$$

It expresses dependence upon the swarm's scaled radial thickness S, and upon the variations of the orbital radius. Here e_t is the target eccentricity, and e_s is the swarm eccentricity. In the important circular swarm case when $e_s = 0$, we obtain

$$F_r = \pi^{-1} S^{-1} \int_0^{\pi} dx \exp[-(R_x - R)^2/S^2]$$

The angular distribution factor, F_a, is given by

$$F_a = 4\pi^{-1}\sigma^{-1} \int_0^{\pi} dc(1 + \cos\alpha)^{1/2} \int_0^{\pi/2} du \exp(-\delta^2/\sigma^2)$$

where

$$\sin\delta = \sin\alpha \sin u$$

$$\cos\alpha = 1 - 2\sin^2 c/2 \sin^2 I$$

and

$$\sin\alpha = \pm 2 \sin c/2 \sin I(1 - \sin^2 c/2 \sin^2 I)^{1/2}$$

The term σ measures the angular spread of the swarm and I is the inclination. This factor expresses effects of the angular width of the swarm and the inclination of the orbits to the equator.

We conclude this report by first going through the calculation of the expected frequency of hits for a typical example. We then elaborate on the effects of these hits and make some final remarks.

Let us consider a navigation satellite of cross-section $A_t = 100$ m^2 whose orbit ranges from 1000 km to 900 km about the earth's surface and whose inclination with the equator is 30 degrees. It follows that its semimajor axis, a_t, is 7310 km and its eccentricity, e_t, is .00684. Suppose there was a billion-pellet ($N_s = 10^9$) retrograde swarm in a circular orbit with height above the earth of 905 km having the same inclination as the satellite. Suppose further that the approximate diameter of this swarm was 10 km. The radial parameter of the swarm diameter $\sigma_r = 2.5$ km, its scaled version S = 0.000342, the angular parameter $\sigma = 0.000344$ and the scaled swarm orbital radius, R = 0.993844. From this information we calculate the estimating factors. The characteristic factor, F_c is (see above) 3.5 hits per year. The scaling factor F_s=0.615, the adjustment factors F_{max} and F_{min} are 1.0194 and 1.0024. The radial distribution factor, F_r, can be numerically calculated as 203. The angular distribution factor, F_a, can be numerically calculated as 7.68. The resulting estimate of the expected frequency of hits is 3372 ± 29 hits per year. If the cross sectional area of the satellite were instead 10 m^2 and the swarm contained 10^8 pellets, we would adjust the expected frequency of hits upon the satellite to 33.7 ± 0.3 hits per year.

Although our model-based analysis did not include the expected relative velocity of hits, it would be characterized by head on relative velocity which in our specific case would be 1.48 x 10^4 m/sec. If the swarm weighed a total of 5 x 10^3 kg, which would be a reasonable payload, then each pellet would weigh 0.05 gm. The resulting impact energy would be 5.48 x 10^3 joules which can be compared to the impact energy of a high-speed rifle bullet, ~ 4 x 10^3 joules. Compared to a rifle bullet the smaller pellets should have greater penetration against almost any armor.

Thus the model appears to have confirmed the potential effectiveness of retrograde swarms as an antisatellite weapon. It would appear to put severe constraints on the reliability and cost effectiveness of any SDI-type system, as well as increasing the scope of potential side effects of an SDI deployment. We strongly urge the consideration of treaties regulating retrograde swarms in particular and the militarization of space in general (3).

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3. A longer manuscript containing calculational details is available from the author.

NEWS

COMING FORUM SESSIONS

New York Meeting, 16-20 March 1987

1. CHERNOBYL, THE YEAR AFTER, Brian B. Schwartz presiding.
   - Herbert J.C. Kouts, Brookhaven National Laboratory, "What happened at Chernobyl"
   - Marv Goldman, University of California at Davis, "The Health and Environmental Impact of the Chernobyl Accident"
   - James K. Asselstine, U.S. Nuclear Regulatory Commission, "The Impact of Chernobyl on U.S. Energy Programs"
   - Robert J. Lifton, John Jay College of Criminal Justine, "The Psychological Aspects of Nuclear Accidents"

Crystal City, VA, Meeting, 20-24 April 1987

1. CONTRIBUTED SESSION, Dietrich Schroeer presiding. Try to attend this, and join in the discussion!

2. BORN CLASSIFIED: PHYSICAL PRINCIPLES OR TECHNICAL DATA? Alexander De Volpi presiding.
   - Steven Garfinkel, Information Security Oversight Office, "An Overview of the Federal Information Classification System"
   - Allan Adler, American Civil Liberties Union, "Legal Issues Associated with Information Classification"
   - William Arkin, Institute for Policy Studies, "Preparation of the Nuclear Weapons Databook from Public Sources"
   - Gerald E. Marsh, Argonne National Laboratory, "The Aftermath of the *Progressive* Case"

3. SOME PERIPHERALS TO STRATEGIC DEFENSE, Caroline L. Herzenberg presiding.
   - Gerold Yonas, the Titan Corporation, "An SDI Perspective"
   - Peter D. Zimmerman, Carnegie Endowment for International Peace, "Multi-mission Role for SDI: Technology and Policy"
   - Darren S. McKnight, U.S. Air Force Academy, "The Effects of SDI on the Space Debris Environment"
   - Steven Aftergood, Committee to Bridge the Gap, "Space Nuclear Power for the Strategic Defense Initiative"

4. BIG PHYSICS/LITTLE PHYSICS COUPLING MODE, Aviva Brecher presiding.
   - Judith Bostock, Office of Management & Budget, "Big Physics/Little Physics: The View from the Budget Office"
   - Benjamin Cooper, Senate Energy and Natural Resources Committee of the U.S. Senate, "Science Policy in the Senate Energy and Natural Resources Committee"
   - Alvin Trivelpiece, Department of Energy, "Advocacy and Budget for Basic Reasearch and Large-scale Physics Within the DOE"
   - Frank MacDonald, NASA Headquarters, "Space Research: Towards a Balanced Program"
   - Donald Shapero, National Research Council, "NRC Role in Setting the Agenda for Physics Research"
   - Mildred Dresselhaus, Massachusetts Institute of Technology," Mechanisms for Secure Funding of Small Science During Fiscal Restraint"

5. FORUM AWARDS SESSION, Paul P. Craig presiding.

1987 SZILARD AND FORUM AWARDS

SZILARD AWARD: To Thomas B. Cochran, Natural Resources Defense Council. The American Physical Society's Szilard Award is given annually to an individual or group who has constructively applied physics in the public interest. This year, the award goes to Thomas B. Cochran for negotiating and implementing a private agreement with the Soviet Union making possible in-country seismic measurements by U.S. and Soviet nationals within the Soviet Union and the U.S., respectively, thereby contributing to verification of nuclear test limitation agreements.

FORUM AWARD: To Richard Scribner, American Association for the Advancement of Science. The American Physical Society's Forum Award is given annually to an individual or group who has promoted the public understanding of the relation of physics to society. This year, Richard Scribner is recognized for developing and implementing the AAAS Program on Arms Control and National Security, thereby making available superb material for communicating to the AAAS community and to the public key issues and background information on arms control and national security.

The Awards Session will be held at 7:30 p.m., Monday, 20 April, at the Crystal City, VA, APS meeting.

FORUM ELECTION RESULTS

Our new vice-chairperson is Barbara Levi. The new members of the Forum's Executive Committee are Martin Einhorn, Anthony Fainberg, and Anthony Nero. Dietrich Schroeer, our present vice-chairperson, automatically becomes our new chairperson.

OPPORTUNITIES IN PHYSICS

Hello again from the Committee on Opportunities in Physics! With this column we resume (after a year's lapse) reporting on COP activities, as started by Earl Callen some seven years back. From responses, we know *Physics and Society* has a devoted readership and we are happy to have this access to you.

Linwood Lee chaired COP in 1986 and Dan Bershader is chairman for 1987. In 1986 COP and Council reexamined the committee goals. Its charge in the APS By-Laws was re-affirmed, with a mutual understanding that the principal task of COP should be to monitor continuously workforce concerns (formerly "manpower") as they relate to physics as a career. Other activities include consideration of a possible APS statement on integrity (see below) and continuation of ombudsman-like activity (none in 1986) in coordination with APS officers.

It is hard not to notice the press coverage on scientific fraud. Media such as *Newsweek, New York Times, Washington Post,* and *Wall Street Journal,* as well as *Nature, Science* and *American Scientist,* have paid it much attention. The more popular the medium, the more general the accusations; e.g., "Fraud and Garbage in Science," (*New York Times,* 29 Jan 1987), although most problems have been in the bio-medical area. COP has discussed whether some leadership statement would be desirable. The consensus is that an affirmation of the integrity of our profession, with examples of potential lapses, appearing in *Physics Today*, is in order. It could subsequently go to new APS members. A draft will be considered by Council in April.

COP workforce activities are considerable. One example is co-sponsorship with Forum of the April 1986 symposium on "The Impact of SDI on the Physics Community", another subject of media attention.

Equally important are regular meetings with the AIP workforce groups, the Manpower Statistics and the Manpower Placement Divisions. The interactions are reciprocally beneficial. COP members are surveying Placement Centers at APS meetings. The record is impressive--the Centers are quite effective. We helped restructure the form used by B.S.-level applicants. We want to publicize other placement services, such as counseling on job searching and resumes.

The Statistics Division is doing a fine job in studying the physics community, job trends, salaries, specialty distributions, etc. Articles in *Physics Today,* the NRC "Brinkman" Report, and talks to Physics Department Chairs by Division Manager Beverly Porter informing physicists of these career aspects. With COP encouragement, the Division developed a do-it-yourself lecture package, e.g. for student group audiences. COP members have volunteered to form the nucleus of a speakers' group. A current concern of COP in this area is how to regard the production of physicists in non-traditional departments, as a step toward assessing the scope of U.S. physics activity.

This brings us up to date. As always your comments and suggestions would be welcome. (Reporting for COP - Israel S. Jacobs, GE Corporate Research and Development, P.O. Box 8, Schenectady, NY 12301)

COMMENT

THE PHYSICAL SOCIETY AND THE LARGER SOCIETY by Sidney Drell

[Editor's note: The paragraphs below are excerpted from remarks made by 1986 APS President Sidney Drell at the final Council meeting that he chaired in November 1986. Drell, winner of the Forum's Szilard Award in 1980 for his work on arms control, is deeply concerned about many of the physics-and-society issues that occupy the attention of Forum members. His remarks to Council are of special interest because they bring out the extent to which APS as a whole is expanding its sphere of activities to include science policy, education, ethics, and the changing sociology of the physics profession.]

Of immediate priority for the Society is the release of the *Directed Energy Weapons (DEW) study,* which was essentially completed in September. It is an important study and I can affirm that the report is of high quality. We must work to get it through its classification review and out to the technical community and the public as soon as possible.

Education and equity. APS made good progress in 1986 with its expanded activities in education. This should remain a high priority. Despite excellent efforts by APS committees (as well as many groups outside APS), the participation of women and minorities in physics remains dismally low. It is urgent that we find new, more effective ways to address this problem.

Industrial physics. The face of physics is changing, and with it the profile of APS membership. More than half of our members now work outside of academic institutions. Having Council advisors from industry has been a valuable step. Also valuable are the academic-industrial linkages being encouraged by the Panel on Public Affairs (POPA). APS activities and governance should fairly reflect the cross-section of our members.

Meetings. The pace of specialization appears to be quickening. Divisional meetings and Topical Group meetings are healthy; general meetings are sickly. It is extremely important that APS sponsor meetings that respond to the needs of its members and, if possible, promote the unity of physics. Imaginative approaches are called for.

Science policy issues. Areas of special concern include (1) the rapidly escalating percentage of Federal research dollars going into military research (a POPA subcommittee is examining this issue); (2) growing restrictions on the flow of technical information (the ever-widening net of restrictions on "unclassified but sensitive" information is ominous); and (3) some erosion of basic science support relative to the support of applied and developmental work.

Finally, I want to raise a question that I touched on at the beginning of my term: In what ways can or should the applications of science be limited when those applications affect human survival? It is a difficult question, and needs much careful discussion. Is there anything that a society can do to suggest guidelines for individual choice?

HOW CAN PHYSICISTS INFLUENCE NATIONAL POLICY MORE EFFECTIVELY?

by Aviva Brecher, 35 Madison St., Belmont, MA 02178

[Editor's note: This article initiates a series by past APS Congressional Scientist Fellows.]

Physicists have traditionally shown a deep concern for uses and abuses of scientific work and technology by Washington policy makers, yet they often simply do not know how to get heard in Washington and influence policy decisions (with few exceptions, such as Carl Sagan, Sid Drell, Richard Garwin and others who occasionally testify in Congress).

During my year of service as 1983-84 Congressional Science Fellow for the American Physical Society, I worked on arms control, as well as on other science and technology issues with Senator Paul Tsongas. I learned a number of useful facts that could aid physicists in lobbying more effectively for change.

First, every congressional office pays close attention to constituents' letters; the staff must answer and record every such letter. Every letter counts, and pro and con mail is sometimes weighed to decide on the member's vote on a given bill. Hence, if you feel strongly about an issue, write to your state representative and be counted. Letter campaigns can be very effective, if properly timed and tied to specific action recommendations.

Further, one can obtain through any representative's office any congressional and federal agency materials of interest: hearings testimony, agency reports and budgets, legislative action logs and text of pending or draft legislation, committee reports, and the "Issue Briefs" and "Info Packs" prepared by the Congressional Research Service (CRS) on the main issues of legislative interest. However, make sure to indicate that your request is urgent, or some intern in the office will give it very low priority. Congress enjoys one of the best information services in the world (Legis and Scorpio, maintained by CRS and accessing all data bases in the nation). Take advantage of it.

On the Hill, issues recur with the annual budget cycle, or the 2 year legislative cycle. Therefore, if you want to influence legislation you must apply pressure in phase. Ideally you lobby with members of key committees dealing with your issues, or with committee staffers. To find out the committee membership, addresses, staffers and telephone numbers, order or buy the U.S. Congress Handbook, a compendium of each Congress, with biographical data on members and a lot of resource information (e.g. maps of the Hill, lobbying tips and more). Call 703-356-3572 to order, or stop in any Washington bookstore during the Washington APS meeting to purchase it.

Timing of letters or visits to Congressional offices is crucial. For example, if you want specific Star Wars program cuts, write, or show up in members' offices just before the Defense Authorization Bill comes to the Senate and House Armed Services Committee for debate. If you missed that deadline, and the bill was already reported out of Committees, lobby hard just before floor votes on the bill (usually in November). If you want funds for Star Wars programs cut, study the budget proposed in January and the DOD R&D Annual Report to Congress, and lobby before the appropriation subcommittees on Armed Services meet. Finally, floor amendments for cuts can be offered in May or June, when the budget bills come to the floor for debate and approval, but you need an incubation time to rally support for an amendment in Congress.

The most effective way to make a difference is to team up with lobbies which have access to Congressional offices. Scientific lobbies I have often called on are: the Federation of American Scientists (FAS), the Union of Concerned Scientists (UCS), the Committee for National Security (CNS), the Arms Control Association (ACA), and the Council for a Livable World, as well as various grass-roots citizens groups. I and other staffers met with these lobbyists on a weekly basis to coordinate legislative efforts in the House and Senate and to exchange information. This Space Policy Working Group is run out of the offices of Congressmen Moakley (D-MA) and Brown (D-CA) in the House, and Senators Proxmire and a few others in the Senate. Do not hesitate to present to these lobbyists and to congressional staffers results of any technical studies pertinent to SDI feasibility or policy.

Another option is to volunteeer to testify in congressional hearings, as expert public witnesses. In setting up hearings on space weapons in the Senate Foreign Relations Committee, I worked with the staffers and invited Garwin, Drell and UCS and FAS spokesmen to testify, and introduced articles from *Scientific American, Science and Nature*, etc. into the Conressional Record.

Finally, you could coordinate your lobbying efforts with the APS Forum on Physics and Society, and the IEEE Society for Social Implications of Technology, the AAAS Arms Control Program, or some other concerned entity, in order to set up public interest sessions at meetings, air views and coalesce consensus on issues affecting the science community and not addressed by professional societies concerned with maintaining an apolitical stance. The Forum carries out studies, presents the results at meetings to educate the membership, and often publishes them through the AIP. These results could be put into appropriate political hands, accompanied by a recommended agenda for legislative action.

For over a decade, fifteen professional societies have been sponsoring Congressional Fellowship Programs, coordinated through the AAAS, not only to lend free expertise to congressional offices, but also to create a cadre of politically sophisticated scientists to better represent and protect the interests of their professional community in Washington. Many past Fellows have caught Potomac fever and have stayed in politically active positions in Washington, or returned to academic jobs while attempting to stay involved in policy. The APS has a list of the names and addresses of these Fellows. Many would be delighted to give your group a talk, share insights, and provide practical advice for moving things in Washington. Morover, if you are interested in an unforgettable educational experience and are willing to take a year off and learn our system of governance first-hand do apply for the Congressional Fellowships, before the program dies from lack of qualified applicants.

FROM THE CHAIRMAN

This column is my last; at the Washington APS meeting I turn my scepter over to Dietrich Schroeer who will, I have no doubt, exercise it with skill, wit and decorum. It's been a good year for the Forum. Our sessions are better than ever, and well attended. The newsletter is reaching new heights. The Forum and Szilard Awards are now official APS Awards, and this year's awardees - Tom Cochran of NRDC and Dick Scribner of AAAS - have done fantastic things. Our credibility has never been higher. We are meeting an important need, and doing it well.

With this issue Art Hobson takes over as editor of the Forum newsletter. Art is a Professor of Physics at the University of Arkansas, the author of two books and lots of papers - the most recent on the vulnerability of land based missiles. His interests are science and society, the nuclear arms race, and jazz. Art's goal is to continue the work that John Dowling and Dave Hafemeister started in making the newsletter a document people will want to keep and reference. Art is getting strong support from his physics department, which pleases me very much indeed. Editing the newsletter is an important contribution to the physics community.

The Executive Committee has given a lot of thought to Forum contributed sessions. We all agree that we need them, but the organization isn't so easy. Contributed papers always include a number of "crackpot" contributions, and there is a natural tendency to put these into a Forum session. That neither helps our image nor makes the sessions interesting.

If we are to have good contributed sessions we need good contributions. These must come from you. When you're writing your physics abstracts, think about writing a Forum abstract too. You probably have a lot to say. There is a "critical size" effect. If only a few of you submit abstracts, things don't work. But when lots of you do - then the pot boils.

Lastly, I want to mention the APS Directed Energy Weapon Study, although it isn't a Forum study. As of this writing it still hasn't been cleared for release by the Strategic Defense Initiative Office of the Pentagon. A strong committee worked long and hard on it, and - amazingly - managed to reach consensus. It will be important for the ongoing national debate on SDI.

It's been lots of fun being Chairman. Dietrich - enjoy yourself too.

Paul Craig

EDITORIAL

I feel honored to be the new editor of *Physics and Society.* The newsletter, and the Forum, are steps toward the further professionalization of the study of the social promises and perils of science. Surely a key theme of our century is the question of the uses and misuses of science. It is fairly clear by now that the rational use of science could provide, to all humans, a level of material well-being available only to kings in ages past, whereas its misuse could doom us all to brief and bitter stone-age lives.

And so it is not enough for physicists to study only physics. For physicists have a unique light to shed, especially on the physics-related problems of society. And it is not enough for us to discuss these problems only informally, in hallways and over coffee. Surely these questions are sufficiently pressing that at least some of us should spend at least some of our professional time analysing them in detail.

In other words, we need to be serious about science and society.

Thus, *Physics and Society* will devote primary attention to original analyses of physics-related social questions. Since they are directed toward other physicists, articles may be (but are not required to be) technical. All articles should be grounded in physics and/or its history or philosophy, i.e. articles should have a physics perspective. It is inevitable and healthy that many articles will take one or another political or philosophical point of view. However, articles tending toward opinion and/or propaganda rather than toward rational and well-substantiated analysis will be rejected.

You will notice a separate "Letters" section in this issue. Unlike articles, letters may be opinionated, especially when commenting on previous articles. Debate is welcome. Letters on new topics are welcome.

It goes without saying (but I am going to say it anyway) that all points of view are welcome. Any biases, e.g. left-wing or right-wing or hawk or dove, that seem to exist in the over-all thrust of the letters and articles will be a reflection only of the leanings of the manuscripts received, and not an expression of the views of *Physics and Society.* So, if you object to any bias you might detect, please submit an article on the other side.

You will notice a "topical" bias in this issue, toward analyses of the Strategic Defense Initiative. The SDI is surely important, but articles are welcome on other topics as well!

Details: Due to space constraints, article lengths should be 0-2000 words including references, equations, tables, and graphs, and letter lengths should be 0-500 words. Brevity is appreciated. Tables and graphs should be camera-ready; we will reduce them to the proper size. A brief non-technical abstract is recommended, especially for the more technical articles. Manuscripts should be typed, double-spaced, styled like other *P&S* articles, and submitted in duplicate. Please use metric units, e.g. Pa or bar or torr or atm instead of psi, although some lapses, e.g. the megaton, may be inevitable.

I thank Dave Hafemeister for his work as interim editor of the newsletter, and especially for his efforts to coach the incoming editor!

John Dowling orginated the Forum newsletter, and maintained and guided it for many years. It is through the efforts of people like John that the science/society interface is finally beginning to attract the professional attention that our times require. My hat goes off to him.

"Desk-top publishing" has turned out to be a more complicated task than either I or editorial assistant Leonora Hermann could have imagined. I thank Leonora for extraordinary perseverance at mastering this skill despite innumerable soft-ware glitches, and for putting together a handsome newsletter.

Art Hobson

ANNOUNCEMENT: INTERNATIONAL CONFERENCE ON TECHNOLOGY, THE ARMS RACE AND ARMS CONTROL.

Sponsored by the Union of Scientists for Disarmament (USPID). Castiglioncello (Livorno), Italy, 25-30 Sept 1987. Main topics: offensive, defensive and civilian space technology; peaceful nuclear technologies and nuclear weapon proliferation; problems of command and control; progress and failures in arms control; non-military justifications for investments in military technologies. For additional information, contact Francesco Lenci, USPID Secretary General; c/o CNR Istituto de Biofisica; Via S. Lorenzo 26; 56100 Pisa, Italy.