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LETTERS

The Gulf War Debate

I was pleased to see the exchange of views on the Gulf War in the April issue. I found myself in 100% agreement with Art Hobson, but Peter Zimmerman's pro-war views contain errors that call for comment.

Zimmerman claims that the embargo against Iraq "leaked like a sieve through Jordan, as munitions captured on the battle field showed." All reports I've seen show that leakage of weapons through Jordan, primarily small arms ammunition, was militarily insignificant. How could Iraq import to any extent when deprived of foreign exchange from exports? Does Zimmerman doubt the CIA's claim that 97% of Iraq's exports (primarily oil) were stopped by the embargo? Iraq was, and is, crucially dependent on imports for food and for military and civilian high-tech items. Even before the embargo, Iraq was having trouble importing military goods because of its huge international debt. And even if Jordan was a sieve, are we to believe that beneficient suppliers of military goods would have supplied Saddam on credit in the face of the embargo? Given the tremendous destruction the war wrought on Kuwait, patience would surely have been the wiser course.

Zimmerman questions if Saddam Hussein could have agreed to back down without a military defeat. Zimmerman, like Bush, ignores the possibility of meaningful negotiations when he claims that Saddam's only choices were "honorable defeat in battle" or "humiliation on the diplomatic front." For those who care to look at the historical record, Iraq expressed a willingness to negotiate itself out of Kuwait a number of times prior to the war. Unfortunately for the Iraqis <u>and</u> the Kuwaitis, any fig leaf for Iraq, however small, was too big for Bush. To avoid negotiating, Bush shamelessly invoked the "Munich analogy" which Art Hobson clearly exposed as fallacious. Maybe negotiations wouldn't have succeeded, but U.S. refusal to even try is beyond excuse.

Zimmerman sings the praises of sold sate physics and the smart weapons it makes possible, with the specious claim that use of these weapons kept civilian casualties to a minimum. As Jack Geiger, former head of Physicians for Social Responsibility, stated after a recent visit to Iraq, smart weapons were used to implement a policy of "bomb now, die later." For example, these weapons made it possible to *efficiently* destroy water and sewage systems in major Iraqi metropolitan areas. This destruction cannot be justified when one remembers that the air campaign effectively interdicted food and water supplies to Iraqi troops on the battlefield. This deplorable U.S. policy forced Iraqi citizens to use water from dirty rivers and streams containing cholera and typhoid germs. Whether intentional or not, the U.S. now bears the burden of waging germ warfare on millions of innocent Iraqis.

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Zimmerman's commentary buys into a variety of assumptions that merit challenge in the Forum, in particular the paean to smart weapons and surgical strikes, and to solid-state physics' contribution to both.

There is no justification for claiming either explicitly or implicitly that the primary reason for using smart weapons was to minimize Iraqi casualties. The primary chain of reasoning seems to have in fact worked this way: loss of U.S. life was to be minimized to avoid losing public support for the war; because of presumed heavy Iraqi air defenses, only stealth technology could therefore be risked over Baghdad; because we only have a few, very expensive stealth "fighters," smart weapons would be required to assure taking out targets. The benefit to the Iraqis may therefore be best characterized as "collateral non-damage." Better views of the U.S. military's commitment to the use of overwhelming force, unrestrained by civil control, may be seen in the slaughter of the Iraqi column retreating north from Kuwait City to Basra.

There is a great political danger in the statement that the possibility of surgical military action has now been demonstrated. For most of its history, the U.S. has been willing to expend resources and people in large amounts in attrition warfare in order to achieve political objectives. But casualties in Vietnam contributed greatly to undermining public support for military action. The lesson drawn by senior military leaders was that casualties, and the information about them, must be kept low. This encouraged the Reagan search for forces and military doctrines that substituted technology, and money, for American lives.

To conclude that advanced technology has demonstrated that it can achieve this ephemeral goal encourages further pursuit of complex technological solutions for all military contingencies. The incentive then grows to increase both the striking power and the distance between enemy and friendly troops. As the distance grows, confidence grows that the key criteria of low friendly casualties will be met and, hence, there is less risk to any given proposal of the use of force.

To assert that the precision of the weapons will now allow the use of military force with little collateral damage encourages the further expansion of the doctrine of overwhelming force. Thus, weapons and systems originally designed and purchased for surgical strikes may be used massively in attrition warfare conducted at a distance from friendly troops, with little ultimate regard for enemy casualties. An example of this attitude was the repeated call during the Gulf War to win the war by airpower, a call which might well have been heeded if the Iraqis had been more wiling, or more able, to fight effectively.

Throughout most of modern history, war was rarely conceived of by any rational leader as in inexpensive alternative to diplomacy. The lessons of the Gulf War as cited by Zimmerman, however, contain the dangerous suggestion that military force can be used as an alternative to diplomatic efforts without incurring great costs —that surgical interventions against small powers are again possible, as they were thought to be during the height of colonial expansion.

It is convenient to say that war with minimum casualties is preferable to the same war with much higher casualties, particularly if one neglects the importance of calculating casualties as a deterrent to going to war at all. Nor is there any reason for implying, as Zimmerman does, that the only alternative was nuclear weapons. The choices were to fight with nuclear weapons, to fight with conventional weapons, or to see fighting at all as too costly, economically, politically, or socially, and put more emphasis on sanctions, embargoes, and other non-military strategies. Just as too much emphasis on 'clean' tactical nuclear weapons has been roundly criticized as providing too much temptation for the first option, the notion of 'surgical' precision conventional weapons provided too much temptation for the second.

The temptation to military adventurism may perhaps be seen by the following startling quote: "The videotape of [the] initial [air] attack, replayed endlessly over those first euphoric days, is the image that most Americans will remember form this war ... At long last, a successor has emerged to the mushroom cloud as the emblem of America's military prowess, and good riddance" (*Newsweek*, Spring 1991, p. 68). This, I submit, is a potentially dangerous intoxication with technology.

For an expansion of the above too-brief argument, see the May issue of *Survival*.

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Response

Frank Munley's criticism hinges on his three assertions: the Iraqi border was effectively sealed; Saddam would have left Kuwait had any fig leaf been offered by the coalition; and smart bombs immorally killed more civilians "later" than iron bombs would have annihilated initially. In reply:

The Jordanian border was virtually transparent to oil trucked out of Iraq as well as to food and even luxury goods imported into Iraq. The number of oil tank trucks destroyed during the first days of the air war (and the protests from Jordan over their destruction) plus the ready availability of Heineken beer in Baghdad even after bombing began are ample demonstration that the embargo wasn't inflicting enough pain to cause Iraqi withdrawal.

As the UN deadline approached, Saddam failed to withdraw and failed to indicate willingness to withdraw. Munley says that Iraq expressed a willingness to negotiate a withdrawal before the war resumed in January, but the historical record Munley cites shows that Iraq annexed Kuwait as its nineteenth province and proclaimed it an inseparable part of the nation. Those are not the words of a nation ready to pull back, and a fair observer must wonder why an aggressor deserves a fig leaf such as an island or two or access to oil beyond its legal boundary.

The choice of waterworks and sewage systems as targets may be questionable, but it is clear that the number of Iraqi casualties, even delayed ones, was far less with precision bombing than it would have been if the Coalition had used saturation bombing with dumb weapons. Surely Munley remembers pictures of Berlin and Tokyo in 1945, and has seen those from Baghdad in 1991; any comparison must favor the use of modern weapons on moral grounds alone. Finally, Munley's charge that destruction of the Iraqi infrastructure is equivalent to germ warfare, such as Saddam Hussein could have unleashed from his anthrax vats at the Salman Pak biological weapons laboratory on the Tigris, is absurd on its face.

Gene Rochlin's thought-provoking response raises other questions: The near annihilation of the Iraqi columns in retreat was a political decision; American war aims called for the elimination or reduction of Iraq's power to threaten the peace of the region, and that, in turn, required the destruction of the Iraqi army, particularly its better units. Sadly for the Kurds and Shiites whom we encouraged to rebel, our own government lost its nerve when it realized that Saddam might be toppled with no strongman there to replace him. The failure to close the gap and to pen up the retreating Republican Guard divisions will surely be counted as one of the greater mistakes in twentieth century military history, since it led directly to the Viet Nam-like quicksand in which U.S., Coalition, and UN troops are now drowning.

The thread running through Rochlin's response, however, is that precision weapons in American hands lead to military adventurism, and that they lower the threshold for war just as he and I believe that tactical nuclear weapons lower the threshold for first nuclear use. I do not think so. Indeed, Congress voted for war even when all of the pundits were predicting tens of thousands of casualties on the Coalition side. The choice was made when it did not appear that we could have military victory on the cheap.

The combination of Iraqi ineptitude, and the overwhelming force brought to bear by the Coalition which made the conflict so one sided are circumstances not likely to recur. Given that, it is probable that future American leaders will not cite the Gulf War as precedent for reckless intervention.

Peace is usually, but not always, preferable to war. It is not merely "convenient to state that" war with fewer casualties—and particularly with fewer casualties among non-combatants—is preferable to "the same war with much higher casualties," as Rochlin puts it. War with fewer casualties is, in fact, preferable to war with higher casualties. Similarly, war with conventional weapons is preferable to nuclear and chemical warfare. There is a hierarchy of preferences to be considered in reaching the decision to fight and then making the choices as to how one will fight, and it is correct to consider the consequences of taking each step up that ladder.

However, Rochlin's argument against the use of precision weapons seems to imply that saturation bombing and imprecise battle field weapons will cause so many casualties (on both sides) as to make war unthinkable. That is not the case, and has not been so at any time in history. Only nuclear weapons have become self-deterring.

But war can sometimes achieve ends not attainable through other actions. Iraqi post-war pleas before the United Nations and its ready compliance with the conditions imposed by the Security council indicate to me that military force produced an outcome which would not have been achieved by sanctions. Furthermore, the destruction of Iraq's Scuds and the imminent dismantlement of Iraq's facilities for making nuclear weapons, of its chemical weapons installations, and its biological weapons laboratory could only be forced upon a defeated enemy. Had sanctions "worked" in the sense of inducing Iraq to leave Kuwait, Saddam would have been left with missiles, nerve gas, biological weapons, and the capability to construct nuclear weapons in the near future.

One criticism which can justly be aimed at the U.S. is the tragic failure of our leaders to contemplate the peace they hoped to secure. President Bush encouraged revolution in Iraq; when it came, he abandoned his creation. We hoped to use the Gulf victory to liberalize the societies of Iraq, Kuwait, and perhaps Saudi Arabia, but took few steps to advance that cause. When forced to choose between splitting Iraq into ethnically homogeneous (and probably stable) states or preserving a unified country under Saddam, we chose Saddam, and thus may have snatched a new Vietnam or Lebanon from the jaws of victory.

Peter D. Zimmerman

ARTICLES

Can the Nation Afford Not to Pursue Research on Aneutronic Nuclear Power?

Bogdan Maglich

[This and the following article form a pair. This article presents the case for research on "aneutronic" fusion reactors, while the following article presents the case for the more conventional DT fusion reactor. *Editor*]

"We may apparently be at the brink of an energy technology which is compact, safe and has virtually no residue but the electricity we see fit to produce with it." Glenn T. Seaborg, 2nd International Symposium on Feasibility of Aneutronic Power, May 1989.

Successes in tokamak fusion research and the proximity to energy breakeven, which is now only about a factor of 3 away, have made it clear that controlled fusion is feasible. It is not clear that a DT reactor can be made economical (unless it breeds plutonium) or that it can be made environmentally acceptable. Hence, quests for the next generation fusion systems that would utilize neutronless and radionuclide-free reactions and compact devices, are underway worldwide.

At the 2nd Symposium on Feasibility of Aneutronic Power, Igor Golovin of Kurchatov Institute reported: "We have just gone through the Chernobyl accident and power production based on fission of heavy nuclei appeared before us in a new light. Neutron multiplication produces a huge radioactivity, against which one needs to protect every living thing. There is an opportunity to create a low-neutron fusion power industry up to a million times less radioactive than contemporary nuclear power production. It will be based on the fusion of deuterium and helium-3."

Physical conditions for aneutronic fusion

A reactor is defined as aneutronic if its *neutronicism*, $\nu = E_n/E \leq 1\%$, where E_n is the energy carried by the neutrons, and E is the total energy generated. The most studied aneutronic reaction is

$$D + {}^3He \rightarrow \alpha + p + 18 \text{ MeV} \quad (1)$$

It is the neutronless, radionuclide-free "mirror reaction" to conventional D+T fusion. whose $\nu > 80\%$ (see Appendix). Equation (1) is accompanied by the neutron-producing D+D reactions: ^3He+n +3.3 MeV (50%) and T+p+4 MeV (50%); the latter does so via DT with secondary tritons. Computer simulations indicate $\nu = 1\%$ (due mostly to DT neutrons) for a D:^{3}He mix of 1:3 in an ignited reactor (energy gain $Q \geq 10^3$). For a driven reactor ($Q \leq 10$), $\nu \approx 0.01\%$, solely from DD neutrons.

As most of the energy is carried by charged particles, Equation (1) should allow direct conversion into electricity, bypassing the need for a heat cycle, thus reducing "heat pollution." Absence of neutrons precludes the reactor's potential for weapons proliferation.

There have been three problems with a D^{3}He compared with a DT reactor: (1) It requires 10 times higher ion energy, T_i, as its *reactivity*, i.e. its fusion cross section times velocity, is optimum at 100 KeV (a temperature of 10^9 K). (2) It requires better confinement at ion density n_i larger by a factor of 2. (3) Energy loss from the reacting plasma increases for synchrontron and bremstrahlung radiation by the factor Z^2. Synchrotron radiation, which is proportional to B^2, can be controlled by reducing the magnetic field B but this is incompatible with better confinement in a tokamak. The bremstrahlung can only be controlled by making the electron temperature $T_e << T_i$.

Industry considers DT fusion unsuitable. EPRI suggested parallel research on aneutronic fusion. Utilities do not believe tokamaks can serve as a stepping stone to aneutronic reactors.

The first two requirements are combined in one parameter, the "energy density," $\varepsilon = n_i T_i$. For aneutronic fuel ε must be about 20 times greater than in a DT reactor. The measure of energy density is beta, which is the ratio of the particles' kinetic energy density to the magnetic energy density of the confining field, $\beta = (8\pi n_i T_i)/B^2$. The average of beta cannot exceed 1; in local regions $\beta >> 1$ is possible, however. Efficient aneutronic fusion requires a high beta reactor, β = 0.9 or greater. In tokamaks, beta has to be below 0.05, for stability. A "second stability region" with $\beta \cong 0.3$ has been postulated.

In alternate confinements such as large orbit mirrors and field-reversed configurations (FRC) higher beta values are possible. In beams, beta is not defined; as the motions are ordered, local beta in excess of 1 have routinely been achieved; e.g. in the Fermilab Collider $\beta \sim 10$ in the beam region.

Beta is determined by the diamagnetic field of the moving particles, which tends to cancel the B that confines them. As beta increases, a "diamagnetic well" will be formed. (A 90% diamagnetic well has been observed in the mirror machine 2X2B). If internal currents are large enough to create a field-reversed region about the plasma center, this would provide an "absolute confinement."

New experimental data, concepts and theoretical calculations, carried out in the 1980s, have either solved in principle, bypassed, or minimized these problems.

Bypassing problem (1)

The advent of *colliding beams* in particle physics offers an alternate method of attaining high T_i. Instead of heating plasmas, ions are accelerated and "fired" head-on against each other. A textbook proof of the impossibility of colliding-beam fusion reactor was circumvented by the invention of self-colliding orbits or "migma" (Greek for mixture). A series of magnetic "self-colliders" were tested, with large radius ion orbits, distinguishing them from small, adiabatic thermal plasma orbits. In the latest, Migma IV, 725 keV deuterium ions were trapped and confined in a disc shaped volume of 150 cm^3 (10cm radius, 0.5cm wide), and neutralized by electrons oscillating through the disc. Ion-electron equilibrium does not result: $T_e/T_i \sim 10^{-3}$. A beam-plasma hybrid physical state was created, for which there is no theory.

The FRC's are also capable of reaching $\beta \approx 1$ e.g. reversed-field theta pinch. The reversed field is self-generated by magnetic com-

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pression of a reversed field trapped in a plasma. To reach T_i=100keV, however, FRC would require a volume of 100 m^3. Currently FRC plasmas are typically < 1m^3, $T_i \approx 0.5$keV and $\beta \sim 0.1$. It remains an open question if FRC can reach D^3He temperature or not.

Overcoming problem (2)

For forty years, plasma instabilities have plagued fusion research. The major problem has been "anomalous transport," differing by a factor of 10-100 from *classically* calculated transport times. Recent experiments (1988-90) in tokamaks, however, (JET, TFTR, and D3D) have demonstrated that, as T_i increases, particles tend to behave classically in the presence of turbulence. Large-orbit ions average the internal fields with a very different result than small-orbit ions; only low energy long wavelength fluctuations can produce convective cells and avoid trapped particle resonances. This is consistent with the observed stability of migma at $n_i \sim 10^{10}$ cm^{-3}, which was in excess of the "space charge limit," density, i.e. 10 times greater than in accelerators. Although a general instability threshold was exceeded the energy confinement time was long, τ_E = 20 sec. In thermal plasma mirrors various instabilities limited n_i to $\leq 10^6$ cm^{-3}.

Even without field reversal, high-β devices will provide better confinement: as $\beta \rightarrow 1$, the mirror ratio $\rightarrow \infty$, greatly suppressing ion losses out the ends. Moreover, high T_i suppresses scattering loss processes: the Coulomb cross section is $\propto T_i^{-2}$, while fusion cross sections increase exponentially with T_i.

Overcoming problem (3)

Diamagnetism reduces radiation losses: if n_i is peaked in the central zone, the charged particles spend most of their time in the central region where B is low. As $\beta \rightarrow 1$, synchrotron radiation loss takes place only at the plasma surface, and becomes independent of B. The cool-off time then becomes longer than τ_E.

Computer simulations (1986-8) of large-orbit D^3He in more advanced confinements (plugged mirror and β=0.95 migma) have shown that D^3He *will ignite* if part of the 15 MeV protons remain trapped to provide a heat reservoir.

Three of the new high beta experiments planned and under way are:

- *FRC experiments* are under way at Tsukuba University (Gamma-10), Yefremov Institute in Leningrad, and Spectra Physics Inc. USA. Theoretical studies of the FRC D^3He reactor are being carried out by a Japan-USA workshop (Nagoya U and U of Illinois).
- *Perpendicular self-collider.* A new theory for the field-reversed self-collider has been advanced by N. Rostoker. In a coasting ion beam of 1 MeV, particles collide perpendicular to the beam direction via betatron oscillations, with internal $T_i \approx 100$keV. A model, to be tested at UCI, uses a high current ion diode injector.
- *Micro-collider.* A miniature self-collider with a 1 cm^3 volume (B=18 tesla) is in preparation by Advanced Physics Corp., in university-industry cooperation at UC Irvine. Its goal is to reach a $\beta \sim 1$, and field reversal. (This would imply a D^3He power density of 1KW/cm^3; a power reactor is envisioned as an array of many micro-colliders, 100-1000 cm^3 in volume each).

Most of the high beta devices require *smallness* for greater efficiency. The cost for an experiment is typically millions of dollars, as compared with the billions for a DT fusion device. Demonstration of scientific feasibility will be nearly equivalent to demonstrating engineering feasibility, since aneutronic reactors are subject to relatively few safety and material destruction constraints.

The parameters achieved simultaneously by 3 types of devices are compared in Table 1.

Table 1. Fusion reactor parameters simultaneously achieved ("supershots").

Parameter	Tokamak TFTR	FRC gamma-10	Coll. beams migma IV	Required for D^3He
1. confinement time, τ_E [sec]	0.5	1	30	1
2. ion density, n_i [cm^3]	5×10^{13}	10^{13}	0.5×10^{10}	6×10^{14}
3. ion energy, T_i [keV]	10	1	730	100
4. product $n\tau_E$ (1)x(2)	2.5×10^{13}	1×10^{13}	1.5×10^{11}	6×10^{14}
5. triple product (1)x(2)x(3)	2.5×10^{14}	1×10^{13}	1.1×10^{14}	6×10^{16}

Helium-3 fuel and plant cost

^3He, a natural nonradioactive isotope, rare on earth, is 10^6 times more abundant on the moon. It has been proposed that NASA mine it on the moon. The advent of the self-collider makes this unnecessary, since ^3He can be bred in the D^3He reactor using the protons from it via the reaction

$$p + {}^6Li \rightarrow \alpha + {}^3He + 4\ MeV$$

Another ^3He breeder is the reaction

$$D + D \rightarrow {}^3He + n + 3.3\ MeV$$

Generally a reactor that can burn ^3He can breed ^3He. Current ^3He cost is 4.5 mil/KWh(th) versus 43 and 47 for T and U238. Economy of mass production (modular power units) will make the capital installation cost less than $500 per KW(e) installed capacity.

Public policy

The US fusion policy is to concentrate all funds towards demonstration of radioactive DT fusion which is claimed to be a "stepping stone" to aneutronic fusion. Arguments advanced by Edward Teller, against parallel aneutronic research, are that DT fusion is "easier" to demonstrate because it requires lower T_i, and that it has collateral benefits: mass production of plutonium.

The electric power industry considers DT fusion "unsuitable for public use" and "unacceptable to its ultimate user—the utilities." Referring to tokamak the utilities stated: "What we don't need from fusion is huge, complicated nuclear plants with many of the same siting, licensing, investment capital, lead time, and public-political relations problems as the nuclear plants we've already got." In the late 1970s, the Electric Power Research Institute (EPRI) suggested the DOE fund a *parallel* research effort on aneutronic fusion. The utilities do not believe that neutronic tokamaks can serve as a stepping stone to aneutronic reactors. When DOE decided against a parallel effort, EPRI phased out its fusion program (1982).

Now that DT fusion has been virtually demonstrated, there is no reason the nation should continue postponing aneutronic fusion. The policy of delaying this nonradioactive fusion research fails to take advantage of new physics and forecloses a major alternate energy option.

Appendix

Neutronic fusion. All government-funded fusion research in the USA, USSR, Western Europe and Japan is a continuation of the "taming the H-bomb" approach of the 1950s, which is based on the reaction

$$D + T \rightarrow \alpha + n + 17.3 \text{ MeV}$$

It uses a 50:50 mix of deuterium and tritium and produced (14 MeV) neutrons. Its basic neutronicism v=80% but because of the use of neutron multipliers, in practice v=90%. Tritium, the radioactive isotope of hydrogen, has a decay period of 12 years; in contact with water it always replaced ordinary hydrogen ("reduced-mass effect"), and forms tritiazed water (HTO), introducing radioactivity into the life cycle.

Energetic neutrons penetrate surrounding materials, making them radioactive. More radioactive waste is produced than that by nuclear fission plants, but it is shorter lived. The waste could potentially be reduced by the use of exotic alloys (not yet tested). Tritium reactors would rely on the massive use of flammable lithium to convert the neutron energy into heat for steam generation; and toxic beryllium to multiply neutrons for tritium breeding.

Two thirds of the energy produced in a tritium reactor would be in the form of waste heat; a tritium reactor of projected optimal size (3000 MW-electric) would contribute to global warming by releasing 3 times as much heat as the largest fission reactors. Engineering considerations indicate that tokamak will also be prone to accidents.

Economic projections predict the cost of tokamak-generated electricity will not be competitive with that of present nuclear plants unless neutrons are used to breed plutonium. The cumulative cost to date of tritium fusion R&D is estimated to be $30 billion (worldwide); the current spending rate is about $1 billion per year. The original plans called for demonstration of energy breakeven of "driven" (not ignited) DT fueled tokamak reactor by 1982. In 1990, a funding request for a new version of tokamak ("ignitor"), to demonstrate ignited DT power production, was put forth by the Fusion Power Advisory Committee to DOE. Its cost is projected at $0.5 - $1 billion.

Tokamak Magnetic Fusion and the First Generation of Fusion Power

Rush Holt

The first generation of fusion power reactors—projected to be tokamaks fueled with deuterium-tritium mixtures—is expected to offer several important advantages compared to other energy sources. Economic extrapolations indicate that fusion reactors have the potential to produce electricity at costs comparable to present methods and others envisaged, and fusion could offer significant safety and environmental advantages as well (1). Furthermore, one may expect the design of fusion power reactors to evolve over the years, using advanced confinement techniques and different mixtures for the hot plasma fuels to provide improved environmental and economic performance. The first demonstration reactor could be built by 2018, although it could happen sooner or later depending on the level of commitment.

Most of the fusion research and development in the world today is based on the tokamak, currently the most advanced design and the most easily extended to reactor scale. The fuel for a fusion reactor is likely to be a mixture of deuterium and tritium (DT), which can fuse at temperatures above 10 keV to produce one alpha and one neutron per reaction. (So far, experiments have used hydrogen or deuterium. DT fuel will be burned in magnetic fusion experiments for the first time in 1993.)

The tokamak has been the mainstay for two decades and provides the best extrapolation to power reactors.

The availability of fuel is one clear advantage offered by fusion. Deuterium is for all practical purposes limitless. For illustration, the deuterium in the top two inches of Lake Erie, if burned in a fusion reactor, would exceed the energy equivalent of the world's oil reserves. Lithium is relatively abundant on land and moreover could be extracted from seawater and used to breed tritium sufficient for millions of terawatt years of fusion. The present world power consumption is less than 15 terawatts. Beryllium, which may be used as a neutron multiplier for breeding tritium, is a more limited resource, but could nevertheless provide centuries of supply (2).

Safety, waste, weapons

Fusion also offers significant advantages in terms of safety, consequences of reactor accidents, and radioactive waste. Tritium fuel would be released into a reactor less than a gram (10 kilocuries) at a time. The limited inventory would mean not only that there could be no runaway reactions in a fusion reactor, but also the reactor could be isolated from the tritium stores so that an accidental venting of the reactor would expose humans at the site boundary to less than a rem. The neutrons, which carry 80 percent of the energy from DT fusion, would be mostly captured for tritium breeding and would pose little hazard if humans are excluded from the reactor vicinity. The structural materials activated by the neutrons would require careful handling. The resulting radioactive waste would not be long-lived and would have essentially no biologically active or volatile components. Except for tritium gas, most of the radioactive inventory in a fusion reactor is bound in the structural materials of the reactor. The maximum plausible dose of radiation to a person at one kilometer from an accidental release would be less than 25 rem, low enough to produce no off-site deaths from acute irradiation, even without active safety systems or containment buildings (2,3).

One measure of the level of the problem of radioactive waste is the dilution index. Less than 100 cubic meters of non-radioactive filler would be required to dilute the radioactive waste from a 1200 MWe fusion plant to meet federal requirements for shallow burial after 30 years of operation. This compares very favorably to the millions of cubic meters of dilution for a comparable fission plant. No intruder who might live or farm at the burial site after more than 100 years would receive more than 500 millirem per year. (By citing this index I do not suggest that shallow burial is necessarily the best method of disposal of wastes.)

Opportunities for improvement to even lower levels of radioactivity exist, including the development of low activation materials—perhaps employing silicon carbide. Coolants and tritium-breeder combinations with less stored chemical energy than liquid lithium, such as LiFBe

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molten salts, or helium coolant combined with stable lithium compounds like lithium silicate, may also become available. A reactor constructed with low activation materials would have one millionth the radioactivity of a fission reactor after one year and one ten-millionth the radioactivity after 100 years (3).

Fusion reactors would present smaller problems than fission plants with respect to proliferation of weapons. There are no fissionable materials inherently associated with fusion reactors, and breeding of fissionable materials would be relatively easier to detect by inspection (1,4).

Concerning D^3He fusion

All this is not to say that fusion without neutrons (see the preceding article by Maglich) is undesirable. Fuel cycles which offer lower neutron production offer an attractive prospect for the longer term. Unfortunately, even D^3He, which is the next easier fuel after DT to fuse, adds daunting challenges beyond the already difficult problems of fusion. Furthermore, D^3He fusion with the associated DD reactions would release 5 percent or more of the energy in neutrons. Thus, a designer would not be freed from consideration of neutron bombardment.

At the same time, the usual problems of heating and confining the plasma are amplified by the use of D^3He. The product of Maxwellian temperature, density, and confinement time, at the most accessible conditions of plasma burn, is an order of magnitude higher for D^3He than for DT. Enriching the mixture in ^3He could reduce the neutron production somewhat. Also, preferentially accelerating the ^3He with respect to the D could ease the heating problem, but one cannot carry the non-Maxwellian approach (such as in a colliding beam technique) very far. The energy of the accelerated particles which fail to react on the first or second pass is lost in thermalization, resulting in a low fusion yield.

The NRC considered alternate fusion fuels and concluded that "the prospect for achieving aneutronic fusion is doubtful."

Several years ago the Committee on Advanced Fusion Power of the National Research Council considered alternate fusion fuels and various configurations proposed for burning them and concluded that "the prospect for achieving aneutronic fusion is doubtful." The panel went on to say that, because low-neutron, high power density devices could be important for future space missions, the US should maintain a modest research effort in advanced fuels as an auxiliary to the standard fusion power program. A report of an advisory panel to the European Community states that it is "too ambitious at present to realize fusion reactors using fuels other than deuterium-tritium," but holds hope for the evolution of advanced fuel techniques in the future.

The tokamak design has been the mainstay of the world fusion program for two decades and provides the best extrapolation to power reactors. Using the tokamak design researchers have reliably achieved plasma conditions approximating those of a reactor, albeit for periods of approximately one second. Numerous alternate designs have been considered and some have been developed substantially. None, however, has approached the performance levels of the tokamak.

Fusion power produced in tokamaks has increased by nearly six orders of magnitude in the past fifteen years to 60,000 W of DD fusion power, which can be extrapolated to 20,000 kW when DT is introduced. Tokamak ion temperatures exceed 400 M degrees (35 keV). The product of plasma density, temperature, and confinement time ($nT\tau$) has been increased by a factor of 10,000 in the same period to 7×10^{14} keVsec cm^{-3}, leaving less than a factor of 7 to reach the reactor regime. Plasma current has reached 7 MA. The plasma beta, the ratio of plasma kinetic energy to magnetic field energy, has exceeded 10%. There remain challenging problems in materials development, non-inductive generation of plasma current, fueling and exhausting reactor chambers, heat removal, breeding-blanket design, and many other areas, but the record of accomplishment is sufficient to inspire confidence that magnetic fusion reactors will be achieved.

Energy research in general does not receive adequate support. The uncertainty in the future energy picture appears to be sufficient to justify spending several percent of domestic energy expenditures on energy research in the US. Now we spend less than one percent. Fusion research has reached a stage where each new device costs hundreds of millions of dollars at least. As long as energy research and development remains poorly funded, there will be little room for any device other than the most promising, which is clearly the tokamak now. This is not to say that the tokamak will ultimately make the best reactor. Nevertheless, there is good evidence that a tokamak reactor, fueled by DT, can be a competitive source of power production offering significant advantages as part of a future energy mix.

The author thanks Tony DeMeo for helpful comments.

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Symposium: Protecting the Space Environment

Physics and Society presents here five articles based on the five talks given at an invited session at the April 1991 APS meeting in Washington, DC. The session was sponsored jointly by the Forum and the Division of Astrophysics. It was chaired by Joel Primack, who presents an overview of the problem in the first article. Primack, a cosmologist, was a leader of the Federation of American Scientists (FAS)/Committee of Soviet Scientists study of space reactor arms control. The space reactor study will be detailed in an article planned for the June issue of *Scientific American* by Steven Aftergood, David Hafemeister, Oleg Priluksky, Primack and Stanislov Rodionov. Gerald Share (second article) is a leading gamma-ray astronomer and codiscoverer of the geomagnetically trapped charged particles from Soviet orbiting reactors. Donald Kessler (third article) is the leading authority on orbital space debris; for his article, P&S could obtain only copies of the author's transparencies, which we reproduce here. Richard Garwin (fourth article) is a leading authority on military and civilian science and technology policy. The fifth article, by Donald Ruby, outlines an FAS-sponsored antisatellite arms control study that he chaired; copies of the full study are available from Ruby or from Steven Aftergood, FAS, 307 Massachusetts Avenue NE, Washington, DC 20002. *-Editor*

Protecting the Space Environment: Overview

Joel R. Primack

The common conception of space is illustrated by movies like *Star Wars*: an explosion occurs, the screen is filled with debris, but a moment later it is empty again. In fact, debris and charged particles injected into near-Earth space are trapped by Earth's gravity and by the geomagnetic field, and they are a hazard until they are removed by interaction with the upper atmosphere. Also, each Shuttle or Titan rocket launch increases the amount of stratospheric chlorine by about 0.03% from exhaust of aluminum/ammonium perchlorate solid rocket fuel, which also produces particulates (1). Thus space is actually a fragile environment, in need of protection by scientists and humanity at large (2).

Light Pollution in and from orbit

Optical "Light pollution" from space increasingly threatens both ground-based and space-based astronomy. The atmosphere is transparent only in the optical/IR and the radio windows. The main problem in the optical is bright satellites, which have increased in number by about a factor of 3 since 1970, while the sensitivity of astronomical detectors has increased by more than an order of magnitude (3). Wide-field (Schmidt).telescope exposures within two hours of sunrise or sunset are now contaminated by a average of five satellite tracks. Among the really silly satellites proposed are cremated human remains in highly reflective cannisters in polar orbit (Celeste Corp.), a ring of a hundred 6m-diameter aluminized spheres (Eiffel Tower 100th Anniversary), and a 1800 m^2 reflective sail (Art Satellite). Reflection even from small satellites and space debris can damage instruments on astronomical satellites such as Hubble Space Telescope (4).

> *Space is actually a fragile environment, in need of protection by scientists and humanity at large .*

Radio The main problem for radio astronomy is unfiltered sidebands from networks of satellites. The Soviet GLONASS navigation satellite system has since 1982 increasingly interfered with radio astronomy with the important OH band at 1612 MHz (5). Two or three of these satellites are now always above the horizon. Their sideband flux densities are so much higher than those from astronomical sources that even far sidelobes of radio telescopes pick up background signals. There was a similar problem from the six U.S. Global Positioning System satellites launched before 1986 interfering with the observations of the 1667 MHz OH band; the more recent GPS satellites have filtered this sideband out (6). Motorola has recently been persuaded by radio astronomers to avoid interference at 1612 MHz from its proposed 77-satellite "Iridium" cellular phone remote communications network (7). Radio astronomers will be pushing for increased protection at the next International Telecommunications Union (ITU) World Administrative Radio Conference (WARC) in February 1992. But it appears to be inevitable that most of the radio window will increasingly fog over.

Gamma Gamma-ray astronomy can only be done from satellites or high balloons. As Gerry Share describes below, both gamma rays, and geomagnetically trapped electrons and positrons, produced by Soviet space reactors have caused serious interference with gamma-ray astronomy (8).

Space reactors

The U.S. orbited one small space reactor in 1964. The USSR orbited more than 30 reactor-powered military Radar Ocean Reconnaissance Satellites (RORSATs) in 1965-1988, plus two higher-altitude "Topaz" reactors in 1987-8. These Soviet space reactors each produced approximately 100 kw of thermal power from roughly 30 kg of high-enriched U-235 fuel. The U.S. is developing a much larger reactor, SP-100, to produce ~2.5 MW with ~200 kg 235U for SDI directed energy weapons or possible NASA uses.

A FAS/Committee of Soviet Scientists group, of which I have been a leader, called in May 1988 for a ban on nuclear power in Earth orbit (9). Our arms control arguments for the ban are as follows.

- It would restrain the weaponization of space. Reactors are probably necessary power sources for directed energy weapons, but they are not essential for any other orbital application.
- It could be a good deal for both the U.S. and USSR, trading off U.S. SDI reactor-powered satellites against Soviet RORSATs, which are the main target of proposed U.S. antisatellite (ASAT) weapons.
- It would be easy to verify because of the infrared, gamma ray, and particle emissions from orbiting reactors.

Our environmental/nonproliferation arguments for such a ban are that:

- Reentry of two of the RORSAT space reactors (in 1978 over northern Canada, and in 1983 over the ocean) has already caused radioactive contamination of the Earth's surface and atmosphere. Future larger reactors such as SP-100 would contain much more radioactivity. Intact reentry could allow recovery of enough high-enriched 235U to make many nuclear weapons.

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- Placing used reactors in ~950 km disposal orbits exacerbates the space debris problem, which is especially serious at that altitude.
- Interference with gamma-ray astronomy could become increasingly serious, if instrumental sensitivity and reactor power both increase.

I want to emphasize that our group does not oppose nuclear power for lunar, planetary, or deep-space applications. Indeed, an FAS report (10) by Steven Aftergood on the Radioisotope Thermal Generator (RTG) aboard the Galileo mission to Jupiter was submitted by NASA to help persuade a judge to allow the launch.

Aftergood recently revealed the secret SDI $40M "Timberwind" project, to develop and test-fly nuclear thermal rockets for launch (11). The hydrogen propellant would be heated by a particle-bed reactor, to achieve specific impulse $I_{sp} = v/g \approx 10^3$ s, a factor of ~3 better than chemical fuels. This idea is nutty. It is not clear where such devices could be safely tested, and it would be foolish to use them until their reliability is established. The problems include disposal of the reactor even if a nuclear rocket launch succeeds, radioactivity in the exhaust, and accidents.

Needed Political Actions

Scientists can foresee problems of which others are unaware. Our dual role in helping to avert a space "tragedy of the commons" (12) is to increase the understanding of relevant basic science, and to define and advocate political actions. My list of such policies is as follows:

- Minimize light pollution from orbit.
- Avoid fragmentation of satellites from accidents or antisatellite weapons tests, the main cause of space debris.
- Do not introduce attack weapons into space.
- Ban nuclear reactors in orbit.
- Develop launch vehicles that do not deplete ozone.

Acknowledgements.

I am grateful to John Galt for sending me unpublished material, to Frank von Hippel for travel support from the FAS Fund, to Steven Aftergood and my other FAS/CSS colleagues for an enjoyable and productive collaboration, and to Ron Ruby and the Stevenson Program on Global Security, UCSC, for additional support for expenses.

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Orbiting Nuclear Reactors and Gamma-Ray Astronomy

Gerald H. Share

Gamma-ray astronomy is moving into a new era with the launch of NASA's Gamma Ray Observatory (GRO). This observatory promises to provide sensitivities to celestial sources over an order of magnitude better than previous missions. Key to providing this capability are various techniques employed to reduce background from naturally occurring sources of high-energy radiation.

However, within the past decade, a strong source of artificial radiation has been identified that could seriously affect measurements made by GRO and more advanced spacecraft. Early in 1980 the Gamma Ray Spectrometer on NASA's Solar Maximum Mission satellite (SMM) began detecting new types of transient events. Detailed studies of these events revealed their source to be Soviet satellites launched into low-earth orbit and powered by nuclear reactors. Gamma radiation from these reactors was detected at distances up to about 500 km. In addition positron-annihilation and charged-particle events were detected when SMM encountered clouds of positrons and electrons emitted by these reactors and stored up to tens of minutes in the geomagnetic field. The rate of these events varied from less than 1 per day to over 30 per day and was strongly dependent on the operating altitudes of the satellite-borne reactors and density of the upper atmosphere.

> *A strong source of radiation has been identified that could seriously affect measurements. Studies reveal the source to be Soviet satellites powered by nuclear reactors.*

Techniques have been developed to predict the occurrence of both the gamma-ray and charged-particle transients in the event that a space-borne reactor is launched during GRO's lifetime. The charged-particle transients are more difficult to predict. At present about 95% of the charged-particle transients detected by SMM can be predicted by a computer algorithm. This prediction capability enables the

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experiments on GRO to be alerted when a reactor-produced transient is expected to occur, and minimizes any losses of date. Other techniques have also been developed to reduce sensitivity to these events.

Two classes of reactor power systems have been orbited by the Soviets: 1) a 2-3 kWe thermoelectric system and 2) a 6-10 kWe thermionic system. Over the next decade only the Soviet Union will have the capability of launching additional reactors into orbit. The last such launch occurred in 1988, and it is not clear at present whether future launches will take place. There are mitigative measures that may be used to reduce any future contamination of gamma-ray astronomy missions by nuclear reactors in low-earth orbits, but they may prove to be expensive. One is to launch the gamma-ray observing satellites into either low-earth equatorial orbits (≈400 km) or into high-earth orbits (apogee ≈70,000 km).

The Orbital Debris Environment

Donald J. Kessler

[This talk is published in outline form only, with reproductions of some of the transparencies. —*Editor*]

Earth carries a "shell" of man-made orbiting material:
- Between 106 and 3 x 106 kg in Earth orbit below 2000 km
- Nearly uniformly distributed in latitude and longitude
- Orbit lifetimes of up to thousands of years

Two most important techniques to control near-term environment:
- Design spacecraft and rockets so they will not explode in orbit
- Tests which may cause fragmentation should be conducted only at very low altitude.

The self-generation of orbital debris:
- Collisional fragmentation can result from random collisions,
- —producing additional fragments,
- —increasing the collision rate
- Stable,.but higher, fragment density would likely result if no further large increases in traffic
- Run-away density could result during next century if debris is left unchecked

Collisional stability determination, assumptions:
- Random collisions between cataloged objects is the only source of future debris
- Target to projectile mass ratio to cause catastrophic breakup is energy dependent and is 1000 at 10 km/sec
- Number of cataloged fragments produced is proportional to mass of the fragmented satellites and is 300 for a 1000 kg satellite
- Current size distribution of satellites and debris is independent of time
- Data from the Dec 89 US Space Command Catalog
- Mass and size data from the R.A.E. Table of Earth Satellites

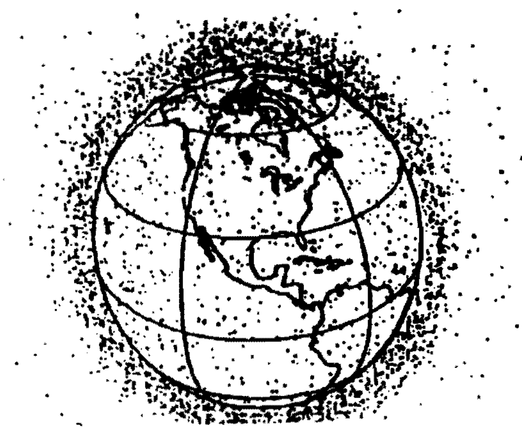
Collisional stability determination, conclusions:
- Orbital debris is likely to increase at 800-1000 km and above 1400 km, even if no new debris is added
- Initial rate of increase is low
- Rate of increase could become high in 20-30 yrs if new objects continue to be added
- —or in 100's of yrs if objects are not intentionally removed

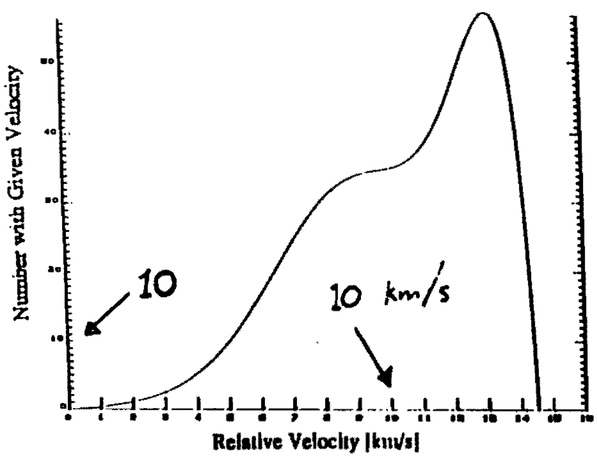
Uncertainties in above conclusions:
- Future solar activity
- Understanding of satellite breakup laws, area to mass ratio
- May have 10-20 years before requiring nothing be added to environment

Current operational practices are to minimize accumulation of explosion fragments:
- Breakup tests are conducted at low altitudes
- Upper stages are vented to prevent future explosions

New operational and design practices are required soon to limit accumulation of larger objects:
- Altitudes should be above 700 km
- Upper stages should have re-start capability
- Rockets and drag devices should be added to payloads

"Snapshot" of Catalogued Objects as Observed from a Point in Space





Relative velocity between spacecraft and debris

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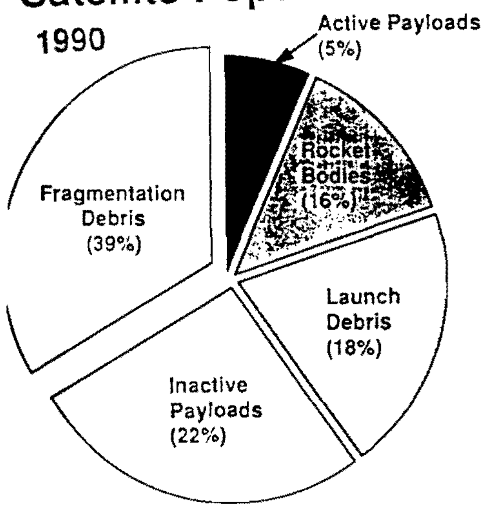
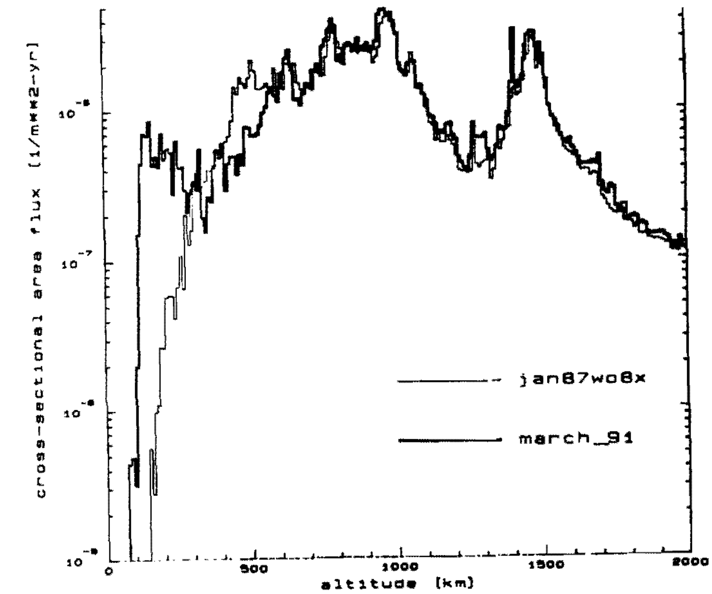
Satellite Population



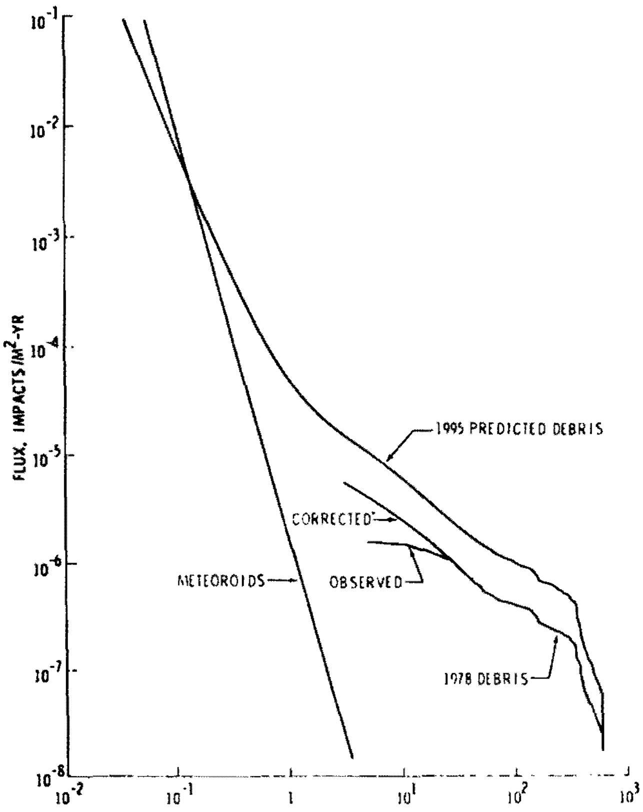
A Comparison of the January 1987 & March
Attributable to Cataloged Objects



Kessler's 1980 Prediction

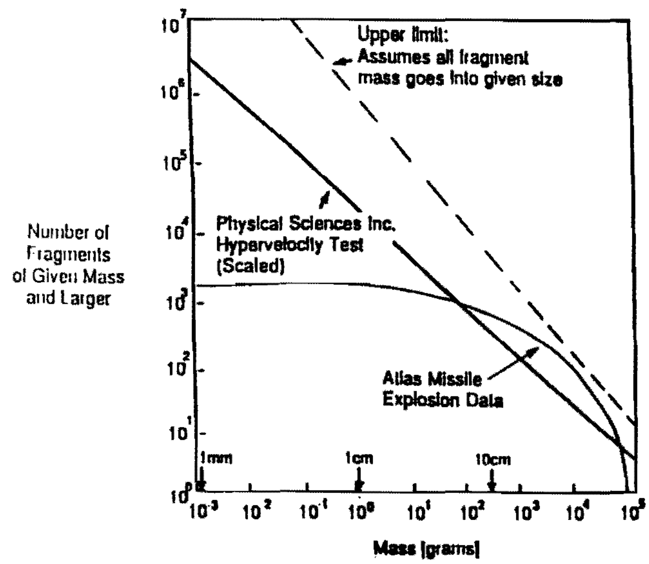
Observed:

Space object	Percentage of tracked population in orbit %
Operational payloads	5
Nonoperational payloads	12
Mission related (rocket bodies, shrouds, etc.)	18
Explosion fragments	54
To be determined origin	11

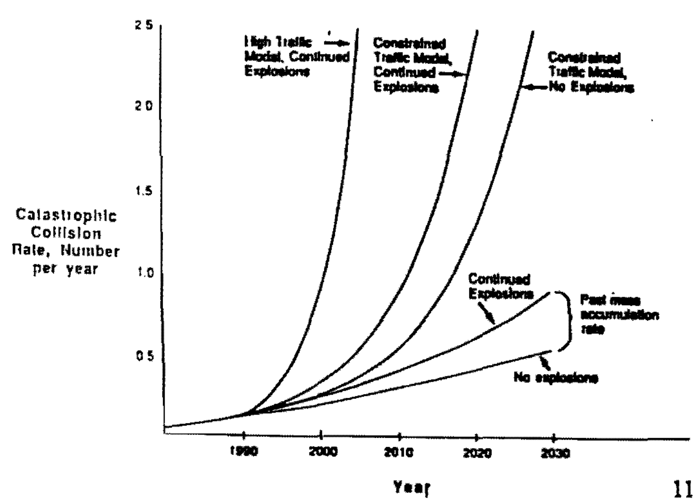


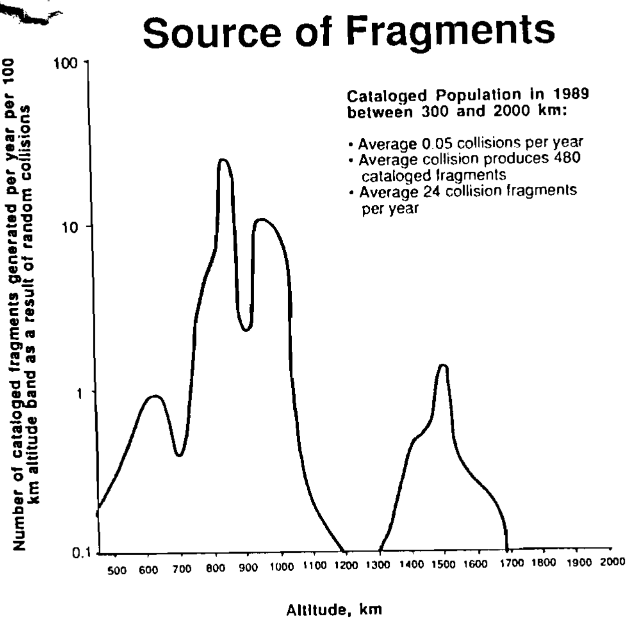
Cumulative flux in 1995 between 600- and 1100-km altitude.

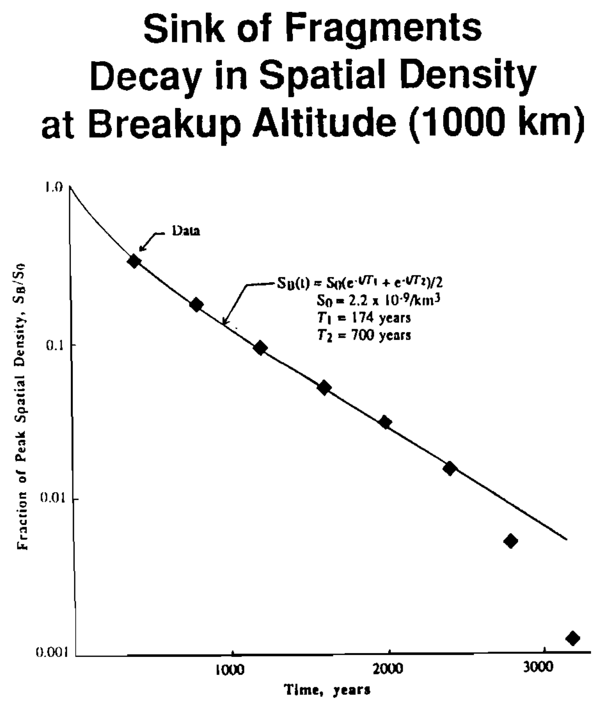
Expected Number of Fragments From the Breakup of a 1400 kg satellite

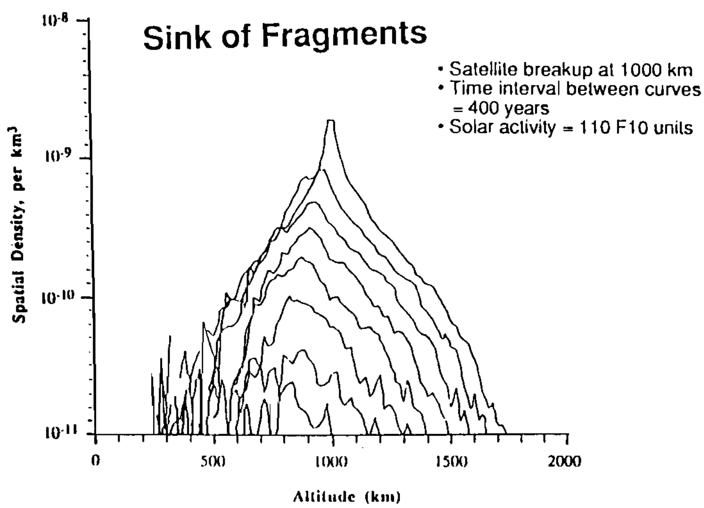


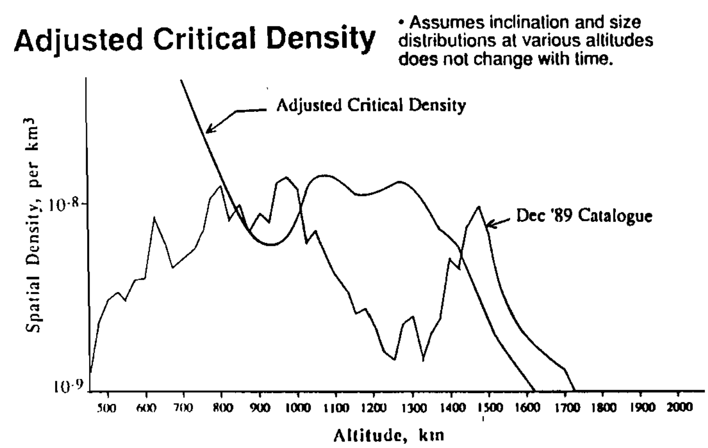
Rate that payloads, spent rocket stages can be expected to catastrophically breakup as a result of random collisions











Weapons and the Space Environment

Richard L. Garwin

In April 1991, prospects for weapons in low Earth orbit (LEO) are poor, assuming that the goal is to provide an augmentation of U.S. national security compatible with the world as it is, as it is likely to become, or as it is influenced by what we can do. But it may happen anyway, through unenlightened self-interest on the part of a military service and its contractors.

There have been extensive writings on the question of space weapons for the last decade or more. Recall that we should sharply distinguish weapons themselves from elements of weapon systems, including very important and capable systems for observation, navigation, communication, etc. The present international regime in no way inhibits the use of space for such purposes; I have long favored, supported, and worked in this area; and it is clear that in the U.S. element of the Coalition activity in the Persian Gulf, we made excellent use of these space assets for essentially all of these purposes. Yes, I would like to deny the use of similar systems to our adversaries during wartime, and support measures which would do exactly that, but without destruction or damage to the satellites of the other side, even in wartime—short of nuclear war.

Space weapons themselves could have as their targets space objects (satellites), missiles that rise into space temporarily, or targets in the air or on the ground. For military targets in the air or on the ground, one is almost always better off to skip the intermediate step of putting an object into space (with a velocity gain of 8 km/s) and then bringing it down again after it has necessarily survived there for some years. Direct delivery from the ground, from ships, or from aircraft (coupled with eyes in space—either those that we have now, or an augmentation in number or kind) will win out, except under very special circumstances.

The Patriot experience

What about the experience in Patriot surface-to-air missile systems (SAM) with its anti-tactical ballistic missile upgrade (ATBM) in

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intercepting a large fraction of the SCUDs launched by Iraq against Saudi Arabia and Israel?

According to SDIO Director Ambassador Henry F. Cooper Jr., SCUD launches were observed by U.S. high Earth orbit (HEO) satellites, which alerted the Patriot batteries and enhanced their innate power to make in-atmosphere intercepts with their air-maneuvering missiles as the SCUD descended toward its target. In his 16 April 1991 testimony for the House Armed Services Committee, Professor Theodore A. Postol assessed the effectiveness of the Patriot in these engagements. Working with data publicly available from Israeli newspapers, Postol showed that damage from an engagement in which the SCUD was "successfully intercepted" by Patriot was somewhat greater than that from a typical unopposed SCUD. Of course, with its inaccuracy of 1 km or worse, disturbing a SCUD in its reentry into an urban area is as likely to divert it to a more valuable target as to a less valuable target.

Enthused by the experience that a ground-based battery can indeed observe an incoming missile and send one or more interceptors to its vicinity, SDIO is urging the deployment of a system providing worldwide coverage from 1000 individual interceptors in LEO ("Brilliant Pebbles"). SDIO is also urging expedited development and probably deployment of "theater-defense" ground-based interceptors based in the United States and in regions of interest to us.

There is every reason to doubt that the Brilliant Pebbles could intercept a SCUD at apogee.

In fact, there is every reason to doubt that the Brilliant Pebbles could intercept a SCUD at apogee, if apogee were held to 100 km, as would be possible even for the extended-range SCUDs used against Saudi Arabia and Israel. And if a theater missile flew high enough so that Brilliant Pebbles could intercept it, it could more readily and more effectively be intercepted by a ground-based ATBM (1). Furthermore, the ground-based interceptor (GBI) could readily handle a substantial number of theater ballistic missiles (TBM) fired at the same time, while the space-based interceptor (SBI) constellation would be hard put to provide more than one or two interceptors in a region in time to intercept at apogee.

The one potential advantage of SBI would be for boost-phase intercept, but the boost phase of TBM ends deep within the atmosphere, and in so short a time that SBI would be of no use. Furthermore, space-based weapons must survive months and years of deployment to be useful, and I believe they will be unable to do so against the opposition the Soviet Union is likely to mount (and that we would surely mount) to oppose them.

Would it not be useful to have the capability on occasion to bring a small non-nuclear explosive or kinetic-energy weapon precisely against a spot such as those that were struck by laser-guided bombs in Iraq? Yes, and I have long advocated the development of missiles that would do exactly that. In fact, you may have noticed that some such missiles were actually used in Iraq—Tomahawk missiles launched from ships, and which could have been launched from aircraft. Similarly, ballistic missiles could well deliver such warheads.

How about space-based weapons for anti-satellite activity—ASAT? The U.S. has given up a program to develop even an air-launched ASAT, in favor of a ground-based ASAT, which is also going nowhere, in large part because of Congressional opposition to such a deployment.

But indeed I would welcome a (conditional) commitment by the U.S. to build and use ASAT to destroy any weapons that might be placed in space by another power. That ASAT should be a missile of very modest performance, launched from the ground with a lot of support from ground-based radar.

ASATs and Brilliant Pebbles

In fact, ground-based ASAT is the nemesis of Brilliant Pebbles, which could readily be shot down by the Soviet Union in peacetime far less expensively than it would cost to put them up. This can be seen very simply from a comparison for the requirements for Brilliant Pebbles and ASAT:

- lifetime—years versus minutes
- sensor range—1000 km versus 100 km
- field of view—1 versus 0.01 steradian
- overall velocity gain—14 versus 3 km/s.

If we were so foolish as to put Brilliant Pebbles (or even "Brilliant Eyes," which may be Brilliant Pebbles with less maneuvering fuel) into orbit, then they will surely be matched or countered by the Soviet Union. The destruction of Brilliant Pebbles by ASAT will leave an enormous amount of debris in LEO. Another means of countering Brilliant Pebbles would be to deploy thousands of tons of dense metal grains in LEO, which at a common crossing speed of 12 km/s would have some 16 times the energy of the same mass of high explosives.

Rather than looking for reasons to put weapons into space, the U.S. would improve its security by resuming negotiations to ban space weapons.

Does the SDIO have the key to making these weapons survivable? If they were truly the size of hornets, probably so, but not a 40-kg Brilliant Pebble. A former SDIO Director, testifying to the House Appropriations Committee in 1987 that even large SDI satellites could be made survivable even against nuclear bursts, volunteered that "a very interesting kind of concept is a tethered satellite...so long...that it exceeds the range of effectiveness of a nuclear burst."

Since a nuclear burst is likely to kill satellites at a distance of 100 km, this is quite a long tether, indeed. But this proposal is neither new nor effective. In a widely circulated manuscript, Hans Bethe and I wrote in 1984, "For instance, in principle a satellite could depart continuously by 100 km from an elliptical orbit by attachment via a 200-km-long tether to a similar satellite—the two rotating about the center of the tether. Two space mines could do the same."

Rather than a remedy to vulnerability, a long tether greatly *increases* vulnerability. No matter how many tethered satellite pairs were deployed on 200-km tethers, over a 500-km altitude band, they could all be swept in a single day by a ton of wire bits deployed in orbit. One does not, with impunity, increase the mutual collision cross section of space weapons from 10 m2 to 104 km^2 (10^{10} m^2) without checking to make sure that the "cure" is not worse than the disease.

The wire bits would not do much good for more compact non-military satellites either. Rather than looking for reasons to put weapons into space, the U.S. would improve its security by resuming and reinvigorating negotiations to ban space weapons and ASAT tests.

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Laser ASAT Test Verification: An FAS-Sponsored Study

Ronald H. Ruby

The study on Laser Anti-satellite Test Verification was motivated by a desire to contribute to an informed public discussion of issues regarding arms control for anti-satellite weapons (ASAT). It responds to unsupported assertions by the Reagan Administration that treaties limiting laser ASATs are not verifiable. The study group was formed at the request of the Federation of American Scientists, which funded the study, and the study workshop was organized and hosted by the Adlai Stevenson Program on Global Security at the University of California, Santa Cruz. The American Physical Society (APS) Study on "The Physics and Technology of Directed Energy Weapons" was a model or the activities of our study group.

The study focuses on the feasibility of verifying compliance with a treaty that restricts the testing of lasers as ASAT weapons by measuring the parameters that might be limited in the treaty. The substance of this study is reported in two sections: One defines the problem, describing the uses and orbits of satellites, their vulnerability to damage by laser radiation, and the required power and apertures of lasers used to inflict such damage; and the other examines several representative types of measurments in order to assess the feasibility of successfully monitoring laser ASAT test facilities to see if they conform to the limitations imposed by a presumed treaty.

The method of analysis was to compare the laser power or energy required to damage a satellite at a specific altitude with the power or energy that could be observed at the threshold of detection in a laser ASAT test using scattering by the atmosphere or by the target. First, in the absence of public information about military satellites, we established the level of irradiance or fluence required to damage a satellite by the two most likely mechanisms of damage, thermal and impulse. Here we relied heavily on analyses and data from the APS Study and simple models. Then we determined the signal-to-noise ratio (S/N) required in our monitoring scheme by considering detection and false alarm probabilities, backgrounds, and various sources of noise. This led to a calculation of the detectable irradiance or fluence on target at three selected altitudes for the two scattering mechanisms (atmospheric scattering and satellite target reflection) and for sensors located on the ground near the laser ASAT site and on surveillance satellites in space. If the power or energy required to damage a satellite is more than that observable at a satisfactory S/N, the laser ASAT test is deemed verifiable.

With treaty agreements for near-site ground-based monitoring, a highly reliable verification regime for laser ASAT testing can be established.

The study participants were Richard Garwin, IBM and Thomas J. Watson Research Center; Freeman Hall, Harrier Consultants; Thomas Karr, Lawrence Livermore National Laboratory; Paul Kelley, MIT Lincoln Laboratory; Donald McNeill, Princeton Research Forum; George Rieke, University of Arizona; David Spergel, Princeton University. Other contributors to the study were Alexander De Volpi, Argonne National Laboratory; Daniel Hirsch, Committee to Bridge the Gap; Norbert Massie, Lawrence Livermore National Laboratory; Richard Muller, University of California, Berkeley; Robert Scarlett, Los Alamos National Laboratory; Frank von Hippel, Princeton University (affiliations are only for the purpose of identification).

A copy of the report summary follows.

Introduction to the report summary

Satellites are an important part of the strategic military capability of the superpowers and, as such, are significant targets. During the 1970s, both the USSR and the U.S. developed "kinetic-kill" anti-satellite weapons (ASATs), which destroy satellites by impact; these weapons were tested with some success against low Earth orbit (LEO) satellites. From 1983 to 1988 the two countries observed a moratorium on further ASAT tests. The U.S. has been able to verify Soviet compliance with their announced moratorium and has confirmed that no Soviet kinetic-kill ASATs have been tested since 1983.

Progress in laser technology has led to the development of high-power lasers potentially capable of damaging satellites. U.S. intelligence reports have been cited as indicating that the USSR has an active program of laser ASAT research. Furthermore, the Strategic Defense Initiative Organization (SDIO) has recently been developing technology for laser ASAT systems. Concerned about the effect these changes have on efforts to achieve ASAT arms control, the FAS commissioned this study of the technical feasibility of laser ASAT test verification.

A laser ASAT may damage or destroy a satellite through rapid heating. The laser's energy, delivered to the surface of the satellite at the speed of light, can melt the satellite's skin, produce structural damage and destroy sensitive components. The laser radiation can also damage or destroy a satellite through impulse damage caused by short laser pulses, where recoil momentum from vaporization of surface material ruptures the satellite skin or disrupts structural integrity. The reported power of contemporary high-power lasers, such as the MIRACL device at the White Sands Proving Grounds, is sufficient, in principle, to incapacitate an unhardened satellite in low earth orbit (LEO). These are not yet fully integrated ASAT systems, however. Structurally destroying satellites in geosynchronous orbits (GEO) will probably require a laser thousands of times more powerful than MIRACL, which is beyond the reach of present technology.

In summary, this study indicates that verification of laser ASAT testing is possible.

A laser ASAT system consists of more than just a powerful laser. An effective system must be capable of acquiring and tracking a target. It must be able to accurately point the laser beam at a rapidly moving satellite using a large beam director mirror several meters in diameter. The system will probably also need an adaptive optics system to correct for turbulence-induced atmospheric distortion and for distortion caused by heating of the atmosphere by the powerful laser beam. Any attempt to develop a working ASAT system must face the challenge of integrating the laser with the adaptive optics, the pointing system, and the tracking system. Each of these components can be tested separately under laboratory conditions, but bringing them into a working system will likely require tests of the complete system against ground and airborne simulated targets as well as against targets in space.

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An arms control regime would protect satellites by limiting or preventing laser ASAT development. A treaty or bilateral moratorium should be adequately verifiable and should be structured so that neither side can clandestinely develop a system to a level where it can quickly "break out" and establish an effective ASAT capability. A variety of technologies and locations could be used to monitor laser ASAT development. In a non-treaty regime, only national technical means (NTM), particularly surveillance satellites, would be available as monitoring locations. In a treaty regime, these monitoring systems would be supplemented or replaced by on-site inspection; in-country monitoring might also be used.

The use of NTM is an essential part of any verification program. Since a laser ASAT facility is likely to be large, surveillance satellites should be able to find and identify potential clandestine sites. Such a site would have to be cloudless a large fraction of the time, as in a desert. In addition to the high-power laser, an ASAT facility will have a large beam director system, target acquisition facilities and large electric power and/or chemical storage systems. Observation of several of these elements at a single site could indicate the existence of a clandestine facility, such sites may warrant continued monitoring of laser emission and/or an on-site inspection.

This report discusses verification of ground-based laser ASAT testing by observing the scattering of laser light in the atmosphere and, if the test target is a satellite, by observing laser light reflected (scattered) by the satellite. We have examined the technical feasibility of using these techniques, either from surveillance satellites or from ground-based monitors placed outside the suspect ASAT facilities. In addition, we have considered the detection of space-based laser ASAT systems. These extremely large satellites are probably identifiable by surveillance satellites or through ground-based observations.

Summary of the study's conclusions

With treaty agreements for near-site ground-based monitoring, a highly reliable verification regime for laser ASAT testing can be established. Without treaty agreements for near-site ground-based monitoring, test verification is less complete but still possible. In the latter situation, testing of laser ASATs intended to attack satellites in GEO can be verified with high confidence by atmospheric or target scattering using a satellite-based monitor. Verification from space of the testing of laser ASATs for attacking satellites in LEO would, on the other hand, depend primarily on observation of target scattering, at a reduced confidence level. No single, simple verification technique can give complete confidence in all cases; acceptable verification regimes can be obtained by combining monitoring of atmospheric scattering, target diffuse reflection and collateral observations.

The following conclusions elaborate on the statement above:

1. All ground-based laser ASAT tests at levels capable of stroying a satellite can clearly be verified by on-site or ne site monitors.
2. The testing of laser ASATs at power and energy levels pable of attacking satellites in GEO can be verified by sat lite-based monitors.
3. Testing laser ASATs with sufficient power to attack satellit in LEO may be verified by observing diffusely reflected lig from test satellite targets.

Comments

Neither off-site ground-based nor satellite monitoring of atmospheric scattering can detect tests below a certain power level. Such low-power tests when combined with high-power tests in an enclosed air-filled tube several kilometers long can help to evaluate much of a system's operability. After such tests, a treaty violator could possibly raise the power, carry out a brief series of tests, and, in a time short compared to the reaction time of the violator's adversary, have a weapons-capable system. Since a laser ASAT has the capability, in principle, of being used repeatedly and rapidly against a number of satellites, a single laser could be sufficient to threaten a large fraction of the constellation of satellites. Thus, rapid "breakout" with a single system may present a substantial ASAT threat, but this should be regarded in the context of other threats to LEO satellites and of possible political and military response to the destruction of satellites essential to national security.

The potential danger of breakout and the possible effectiveness of a single weapon suggest that an ASAT treaty should not merely establish a power or energy threshold for laser tests against satellites under realistic conditions, but should also ban the development of certain classes of laser weapons systems. The ban would be on the construction of an integrated system consisting of a high-power laser, fast beam director, tracking and pointing system, target acquisition capabilities and adaptive optics.

In summary, this study indicates that verification of laser ASAT testing is possible. However, the question of feasibility is most clearly answered by a demonstration of working equipment, showing the detectability of laser ASAT tests. The process of implementing a laser verification sensor requires an exhaustive study of the hardware concepts and options. This needs to be coupled with a thorough analysis of treaty options, which in turn should resolve questions regarding the requisite precision of measurement, detection and false alarm probabilities, and susceptibility to countermeasures and/or breakout, since these criteria set the requirements on monitoring equipment.

REVIEW

Verification Monitoring Disarmament, edited by Francesco Calogero, Marvin Goldberger and Sergei Kapitza.

Westview Press, Boulder, CO, 1991, 266 pages, $32.50.

The book jacket symbolically says in English and Russian: VERIFICATION / BEPNΦNKAUNR. Over the past 35 years, the Pugwash movement has brought together scientists from both sides of the iron curtain to search for ways to lessen the dangers of the arms race. Even after the demise of the Berlin wall and the Warsaw Pact, the Pugwash movement continues to search for ways to enhance meaningful arms control treaties between east and west. This monograph gives the background detail on a number of arms treaties, and how one could monitor them to ensure compliance.

Because a discussion of the many treaties (ABM, ASAT, TTBT, CTB, START, CFE, CWC, BWC, Open Skies, fissile cut-off, warhead dismantlement) is beyond the scope of this review, I have chosen to discuss the verification regime for only one of the treaties. I have chosen the Conventional Forces in Europe (CFE) Treaty because it probably will be under consideration by the Senate about the time of the July issue of P&S.

Arms control reached its peak on 19 November 1990 when the CFE Treaty was signed in Paris. At that point everything seemed possible as both sides seemed willing to continue to accept more intrusive inspections. The vision of deeper cuts danced in the dreams of those who believed that international law though arms control treaties are the only way to prevent a bad end for our Earth. Because the Soviet military backtracked against a weakened Gorbachev on the Soviet naval infantry, suspicions have risen and all arms control stopped, held hostage to the CFE issue. There are some hopeful signs at this writing (May 1991) that it can be worked out. Without a Soviet shift on CFE, the political possibility for further arms control will be dimmer for some time.

The root cause of the problem was the changing military circumstance for CFE. During the 20 months of negotiation, one nation ceased to exist and five changed their names. Because of the demise of the Warsaw Pact (WP), the CFE became much less of a bargain to the Soviets as the WP/NATO power ratio changed from 1.5 (in 1988), to 1.0 (CFE), to 0.67 (no WP), to perhaps 0.5 (WP joins NATO?).

The Pugwash verification book is a useful summary of the verification options and practices for each of the many treaties.

Since the Pugwash verification book was finished in the spring of 1990, it displays the thinking of scientists who wished to maximize the effectiveness of CFE verification with high-technologies. These scientists wrote without the knowledge of the final product of November 19. As it turns out, tagging of treaty limited equipment was not adopted in CFE because it was too cumbersome and intrusive. Production monitoring with perimeter-portal monitors was also not adopted because it was too cumbersome, and because the U.S. is not in the Atlantic-to-the-Urals region. The approach adopted in CFE is low-tech, combining data declarations and follow-up on-site inspections (OSIs) to determine the accuracy of the declarations. It is generally agreed that this approach is more than sufficient to observe a 20% violation, which is considered "militarily significant."

The authors correctly point out that: "Perhaps the greatest difficulty in designing a conventional verification regime will be the temptation to strive for technical elegance without regard for the political and economic costs involved" (p. 173).

It has certainly been useful for scientists to develop various means of tagging treaty-limited equipment because it has shown what could be done in a variety of ways at varying degrees of cost and intrusiveness. Some of the tagging methods are: (1) surface roughness tags, (2) reflecting particle tags, (3) electronic tags, (4) remotely readable electronic tags, and (5) ultrasonic tags. Some of the sealing methods are: (1) the cut and wire seal, (2) the fiber-optic random pattern seal, (3) the fiber-optic electronic seal, and (4) the adhesive label random pattern seal.

The perimeter-portal monitoring schemes that were used in the Intermediate Nuclear Forces (INF) Treaty are discussed, along with the monitoring of take-offs and landings of aircraft with various unattended high-tech sensors. Of course, all of these schemes would be backed up by National Technical Means (satellites, etc.), data declarations and OSIs. Although it was very good for the INF Treaty that the Department of Defense had done the development on some of these technologies in advance, it is not clear how much high-tech verification will be adopted in the future. Too much detail on individual tanks does give additional information, not only for targeting, but also for understanding the deployment practices and technologies of the other side. For the time being, it would seem that low-tech verification is in, and high-tech verification will be in the wings.

The Pugwash verification book is a useful summary of the verification options and practices for each of the many treaties. Perhaps, even more importantly, the exercise of preparing this book is a healthy sign of cooperation between the two superpowers. The world is not yet out from the shadow of the nuclear dragon, and these kinds of cooperative efforts can only help reduce the dangers by transmitting useful ideas—both technical and policy—on the verification of arms control treaties across the oceans.

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NEWS

[You may have noticed that the news section generally contains an overabundance of exclamation marks. These are intended as calls to Forum members and others, especially you, to become active!]

Forum Energy Study Published

The American Institute of Physics recently published the Forum's study on the energy future, the third in a series of Forum-sponsored science-and-society studies. Titled *The Energy Sourcebook: A Guide to Technology, Resources, and Policy*, it is edited by Ruth Howes and Tony Fainberg. The other two Forum studies are Civil Defense: A Choice of Disasters (AIP, 1987) and *The Future of Land-Based Strategic Missiles* (AIP, 1989). A fourth study, this one on conventional weapons systems, is in the planning stage (see announcement below).

The book, written by a broad APS-Forum study group, presents a balanced, comprehensive overview of future energy choices, and provides the general reader with the technical grounding necessary to understand these choices. As in other Forum studies, the views are those of the authors and are not necessarily representative of the Forum. Contents include: summary, energy overview, risk estimation, energy storage, transportation, agriculture, energy efficiency in manufacturing, buildings, appliances, and motors, and the full range of energy resources including coal, petroleum, natural gas, unconventional petroleum, fission, fusion, photovoltaics, solar thermal, hydro, geothermal, ocean, biomass, and wind.

A review, and articles based on some of the book's chapters, are planned for the next issue of ***Physics and Society***.

A New Forum Study: Conventional Weapons and Warfare!

The war in the Persian Gulf demonstrated the importance of conventional weapons. With a thaw in the cold war, regional conflicts have become prominant in U.S. policy. Conventional weapons and their technologies promise to play an increasingly important role.

The Forum on Physics and Society proposes a study to evaluate conventional weapons technology. The study will explore specific weapons and the scientific principles behind them. It will include precision-guided munitions, fire-and-forget missiles, intelligence gathering and C3 technologies, fuel-air explosives, anti-personnel weapons, anti-tactical ballistic missiles and other appropriate weapons technologies, especially those used in the Gulf War. This information will form a basis for discussion of policy issues such as military budgets, procurements and non-proliferation policies.

Like previous Forum studies, participation is open to any physicist! There will be some travel funding to attend study group meetings. If you are interested, please contact Peter Zimmerman, George Washington Univ, Dept of Engineering Management, Melvin Gelman Library Room 639, Washington, DC 20052, 202-994-6433; or Ruth Howes, Physics & Astron, Ball State Univ, Muncie, IN 47306, 317-285-8868, BITNET 00RHHOWES@BSUVAX1! Please provide information about specific topics in which you might be interested and any relevant information on your background.

1991 Forum and Szilard Awards

This year's Forum Award for promoting public understanding was given to Victor Weisskopf of MIT "for his life-long effort to stimulate public awareness of the beauty of science and the dangers of its abuses." According to the official nominating letter, "Throughout his career Prof. Weisskopf has been concerned with the impact of scientific and technical advances on societal issues. After the use of the atomic bomb, his main objective was and is to remove the threat of the atomic and later the hydrogen bomb to world peace. —He continues to be active to this day, adding on a concern for environmental issues."

This year's Leo Szilard Award for the use of physics to benefit society was given to John Gibbons, Director of the U.S. Congressional Office of Technology Assessment (OTA), "for leading and greatly strengthening the OTA, an institution that has produced balanced, thoughtful, and influential assessments of public policy issues dealing with science and technology." Gibbons, according to a nominating letter, "has over the past decade led and greatly strengthened an institution that has become known for its balanced, thoughtful, and influential assessments of public policy issues dealing with science and technology."

Articles based on the award lectures are planned for a future issue of *Physics and Society.*

Forum Election Results and New Officers

The Forum's recent election produced 1042 voters, 24% of the Forum membership and a larger-than-usual turnout. The newly-elected officers are Anthony Fainberg as Vice Chair, Barbara Levi as Representative to the APS Council from the Forum, and three new Forum Executive Committee members: Lawrence Badash, Cindy Schwarz, and Julia Thompson.

The Forum's previous Vice Chair, Ruth Howes, now moves to Chair, while Tom Moss (Chair, 1990-91) and Richard Scribner (Chair, 1989-90), are atuomatically members of the Executive Committee.

The complete list of Forum Officers for 1991-92 is as follows:

- Chair: Ruth Howes
- Vice Chair: Anthony Fainberg
- Secretary-Treasurer: Henry Barschall
- Forum Councillor: Barbara Levi
- Past Chairs: Tom Moss, Richard Scribner
- Executive Committee: Lawrence Badash, Cindy Schwarz, Michael Sobel, Alan Sweedler
- Newsletter Editor (non-voting): Art Hobson

Nominations Sought for APS-Forum Awards, APS-Forum Fellows, Forum Officers, APS Committees!

The Forum is primarily responsible for two of the APS's annual awards: The Forum Award for promoting public understanding of issues at the interface between physics and society, and the Leo Szilard Award for the use of physics for the benefit of society in such areas as the environment, arms control, and science policy. The 1991 Forum Awardee is Victor Weisskopf, and the 1991 Szilard Awardee is John Gibbons (see announcement above). Send nominations and supporting information by 1 September 1991 to Rustum Roy, Materials Research Laboratory, Penn State University, Park Place, PA 16802!

The Forum also nominates, for APS Fellows, those who have rendered some special service to the cause of the sciences, through contributions in science-and-society. Send your nominations for Forum-sponsored APS Fellows, with supporting material, by 1 September 1991 to Michael Sobel, Physics Department, Brooklyn College, Brooklyn, NY 11210! This year's newly elected Forum-sponsored Fellows are Lew Allen, Gene Rochlin, and Peter Zimmerman. For their citations, see the April issue.

For next year's officers, the Forum needs to fill the following positions: Vice-Chair, Chair-Elect, Secretary-Treasurer, and two members of the Executive Committee. Send nominations, with supporting material, by 1 September 1991 to Leo Sartori, Physics Department, University of Nebraska, Lincoln, NE 68588!

The APS is seeking nominations for several important committees, several of which have societal impacts. Forum members should participate in these nominations! The APS seeks candidates for three-year terms on each of the following committees: applications of physics, Consitution and Bylaws, education, fellowship, minorities in physics, membership, international freedom of scientists, the status of women in physics, investment, publications, representative to AIP governing board. For a nomination form, contact Evelyn Bernstein, APS, 335 East 45th Street, New York, New York 10017! Nominations are due by 2 August 1991.

Another APS Forum: on Education

The term "the Forum" recently became ambiguous There is now another APS Forum. Its purpose is to give the APS active research community input into educational efforts.

The new Forum was debated at length, according to APS Associate Executive Secretary Brian Schwartz. The idea had been discussed informally for a number of years, and was first brought up formally in an exchange of letters three years ago between APS Councillor Stuart Crampton and Jack Wilson, then Executive Director of the American

Association of Physics Teachers (AAPT). Both groups were concerned with possible interference between the new Forum and the role of AAPT in physics education. After considerable debate within both the APS and the AAPT, an APS Task Force was formed to investigate the idea.

Schwartz expects that the Forum on Education will attract over 4000 physicists, some 10% of APS membership, and roughly the size of the Forum on Physics and Society. Unlike Divisions, APS Forums (Fora?) do not require a separate membership fee.

The new Forum is intended to complement, and not compete with, AAPT. Cooperative programs in education will strengthen both organizations' educational efforts. Although membership is open only to APS members, a strong role in governance will be set aside for APS members who are also members and leaders of AAPT.

International Forum on Global Change!

Sigma Xi, the scientific research society, and five other associations, will sponsor an international forum on "Global Change and the Human Prospect: Issues in Population, Science, Technology, and Equity," in Washington, DC, 16-18 November 1991. The forum will address the generation of knowledge, formulation of policy, and transformation of society that are required to achieve a sustainable and equitable world. Through plenary sessions and breakout groups, participants will explore three important questions: What kind of world do we have? What kind of world do we want" What must we do to get there? Speakers include DuPont Vice President E.P. Blanchard, OTA Director Jack Gibbons, Mexican anthropologist Lourdes Arizpe, William C. Clark, Lewis Branscomb, Ashton Carter, and World Conservation Union Director Martin Holdgate. For registration information, contact Nancy Berry, Forum Coordinator, P.O. Box 13975, Research Triangle Park, NC 27709!

Read Any Good Books Lately?!

If so, and if P&S readers might be interested, consider sending us a book review! Reviews can be 200-1000 words. They should summarize the book, point out significant features and perhaps draw comparisons with other books. Reviewers' opinions are welcome, but should occupy at most a minor portion of the review.

Join the Forum! 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 free to Forum members and libraries. Nonmembers may receive it by writing to the editor; voluntary contributions of $10 per year are most welcome, payable to the APS/Forum. We hope that libraries will archive *Physics and Society* ; Forum members should request that their libraries do this.

APS members can join the Forum and receive *Physics and Society* by mailing the following information to the editor or to the APS office:

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

NAME (print) ______________________________

ADDRESS ______________________________

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COMMENTARY

From the In-coming Chair:

These are interesting times for the Forum on Physics and Society. Both the American Physical Society and the world are changing as I write. Our Forum must respond to these changes. Our present actions may well determine the future effectiveness of our organization.

Within the APS, the Forum has achieved maturity. Physicists have made and continue to make unique contributions to the solution and understanding of problems in weapons technology and effects as well as in energy and the environment. The Forum recognizes and supports their efforts through sessions at APS meetings, awards of fellowship, the Szilard and Forum awards, the Forum studies and *Physics and Society*. We must continue and strengthen these efforts.

At the same time, the Forum on Physics and Society is no longer the only forum within APS. A new Forum on Education (see News article, this issue) has already been established. We must work this year to establish our unique character within APS and simultaneously forge channels for cooperation with the new forum. Certainly many of us are sincerely concerned about physics education.

While our past activities have been strong, we must think of new means to involve more members actively in the work of the Forum and to better inform the membership of the APS concerning social issues affecting each of them. Each of us should persuade a friend to join the Forum on Physics and Society so that our membership will remain strong. Remind your colleagues that Forum membership is free for the trouble of checking a box on your APS dues sheet and that it brings a subscription to *Physics and Society*. Not a bad bargain!

Recent global events have shifted concern in the physics community from issues concerning nuclear weapons to conventional weapons and raised concern about proliferation of both nuclear and conventional weapons technologies such as ballistic missiles. A growing global perspective has refocused attention on environmental issues which transcend national borders. We must respond to these changes in concern by focusing more time and talent on these subjects. Members should raise their concerns to Forum officers and suggest new study topics, programs or other ways in which we can keep up with our rapidly changing world. Perhaps we should emphasize technical issues of relevance to developing nations, or other issues where we have done little work in the past.

Are there other mechanisms we should be using to more effectively provide solid technical input to the policy making process? As an organization of physicists, our strength lies in the area of physical analysis, and we should deal with issues that are primarily technical. Although technical issues frequently impact policy and we each take individual stands, the Forum as a whole must safeguard its reputation for impartial scientific analysis.

These changing times provide exciting opportunities for the Forum to grow. I would welcome your ideas and opinions. My phone is 317-285-8868 and I'm on bitnet at 00RHHOWES@BSUVAX1.

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Nukes in the Gulf: A Retrospective View

[The author, a nuclear physicist, was founder and first editor-in-chief of *Nuclear Waste Management and Technology*, now in its tenth year of publication as *Waste Management*.]

The use of tactical nuclear weapons in the Gulf was discussed by this writer in a series of articles in the *New York Tribune*, from the August invasion of Kuwait until the *Tribune* ceased publication on 3 January 1991. There was virtually no other public discussion of the nuclear option until congressman Dan Burton of Indiana broached it on a *Crossfire* program in January. In view of the heavy media silence surrounding the issue, it was remarkable that a public opinion poll in January showed that as many American supported use of nuclear weapons as opposed them.

The powerful silent support for use of nuclear weapons almost certainly grew as D-day approached, and was the consequence of the many dire media warnings of the heavy cost in American lives of military intervention in the Gulf. In fact, both Congressman Burton and the undersigned strongly emphasized the savings of lives on *both* sides of the conflict if we used our battlefield nuclear weapons.

In view of the happy outcome of the war from the point of view of the very small number of casualties sustained by coalition forces, it is now obvious that use of nuclear weapons was superfluous from the point of view of reducing *our* losses. But as the extent of damage to Kuwait and Iraq and the loss of life in Iraq —now estimated at 100,000 —becomes clear, a retrospective evaluation of the use of nuclear weapons strongly suggests that it would have been the humane option from the point of view of the victims in Kuwait and Iraq.

Nuclear weapons would have been the humane option.

Burton and this writer argued that prompt response with a few nuclear weapons after a massive public alert, such as we used in Japan, might have brought a negotiated peace in something like the 8 days that elapsed from our first strike against Japan on August 6, 1945, till surrender on August 14, 1945. The very same timetable could have been enacted just 45 years later. Why was it given so little consideration, and why did one often invite furious hostility just by raising the question?

The answer lies in the 45 years of nuclear pacifism that followed the nuclear bombing of Japan. Those bombings had fastened an image in the public mind which equated nuclear weapons with mass destruction. There had been almost no public discussion of the physical and psychological effects of nuclear weapons designed for limited destruction of key targets, although thousands of such weapons had been in the NATO arsenal for decades.

The problem of fostering open discussion of nuclear weapons was further compounded by the nuclear phobia infecting public consciousness due to the hammering of anti-nuclear themes in the media that has brought nuclear power to a standstill in this country.

As we review the Gulf experience, it seems entirely reasonable to suggest that early, selective, fully advertised use of nuclear weapons in the Gulf might have saved 100,000 Iraqi lives and the destruction of their industrial infrastructure. It would have saved many Kuwaiti lives and $100 billion worth of destruction in that country. It would have saved $100 billion worth of costs in moving an army of half a million soldiers to the Persian Gulf. All that could have been saved by launching a few nuclear strikes from carrier-based aircraft already stationed in the Gulf.

Is the foregoing a criticism of President Bush and his policy-makers? Not at all. Given the state of mind of the public after 45 years of nuclear brain-washing by issue-seeking demagogues and easily misled scientific illiterates, nuclear weapons had become politically unthinkable.

So who is to blame for the fantastic costs of the Persian Gulf war? Is it not those who have infected the public mind with nuclear phobia?

Who is to blame for the costs of the war? Is it not those who have infected the public mind with nuclear phobia?

Perhaps what will emerge from this costly experience will be a willingness to think about nuclear matters with our minds rather than with our media-conditioned reflexes. We are approaching the end of the era of fossil fuels and it is a matter of top priority to find replacement fuels. The nuclear energy option has been a victim of the same nuclear phobia that blinded and betrayed us in the Gulf War. Perhaps what will emerge from the war is not only a new political era in the Middle East, but a new openness to nuclear power as a long-term replacement for fossil-fuel power.

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The Gulf War: Appeal from French Scientists

[Editor's note: This was first published in *Le Monde* on 6 February 1991, and signed by 616 French scientists. It was submitted to *Physics and Society* by Nina Byers of the UCLA Department of Physics.]

From the intense, systematic bombarding of Iraq to the blind missile assaults on the Israeli population, from the humiliation of the captive pilots to the destruction of the Baghdad suburbs, an implacable machine has just been turned on. How much more destructions, suffering and pain are concealed by the censorship of the military headquarters? The little we do know suffices however to make us understand that the infernal spiral of war will, in its madness, require an increasing number of counter attacks and counter-counter attacks, unceasingly widening the scope of destruction and death. From mourning to humiliation, from aggression to destruction, all relationships fall apart one after the other and all those who would promote dialogue and peaceful resolution of the innumerable problems of the Near and Middle East are reduced to powerlessness.

Swept forward by its own murderous logic, the war escalates every day and has perhaps already surpassed the levels of previous wars in Vietnam and Afghanistan. From military to industrial objectives, from economical to psychological objectives, from tactical to civilian objectives, the road is familiar. It is a road paved with tombstones. And at the end of the road, after many disasters, not the least of which is an ecological catastrophe, none of the problems will be settled which the war pretended to solve. In the development of this logic nothing is sure and everything is possible.

We, scientists of all disciplines and all political, philosophical and religious opinions are deeply distressed by the unfolding drama.

We suffer as we watch the knowledge and technology we helped create being used to improve the means of terror, humiliation and killing. The initial illusion that this would be a "clean" war because it is technological and "scientific" is replaced by the implacable necessity of war: you have to hit hard and hurt, hurt a lot. And unfortunately, technology has also contributed in this area, filling the arsenals with the means of terror, anti-personnel weapons, fragmentation bombs which cruelly mutilate flesh, chemical weapons which burn and kill, nuclear weapons at the ready.

We suffer as we watch the knowledge we helped create being used to improve the means of terror, humiliation and killing.

The senseless cost of this war appears to us as an insult to those people who suffer from underdevelopment, hunger and misery. How many food rations will disappear with the flight of a single missile? And how heavily will the price of the war weigh in the economic life and in the development of our own countries?

Our work as scientists leads us to form many relationships across borders with colleagues throughout the world. This cooperation, indispensable for scientific work, makes us perhaps more sensitive than others to the human importance of the variety of peoples, civilizations and opinions. We know that maintaining a state of war will undoubtedly destroy for many years the relationships carefully woven between peoples. War frees aggressive impulses, reflexes of fear and suspicion, racism and intolerance. Because it needs unified opinions, it has a tendency to set up its own requirements to restrain the right to careful thinking, the right to diversity, and to limit freedom. Whatever our opinions on the causes of the conflict, on who is responsible for its beginning, on the exact way to resolve the difficulties in the region, we think it is time to react and say all together, "Enough!" We must stop the war and resume the dialogue.

We call on our scientific colleagues to ask our governments to stop the war and start negotiating.

We know it is not an easy thing to do. But there is no other choice if we want a durable peace in the end. To stop the hostilities and begin real negotiations is not equivalent to yielding on the annexation of Kuwait. We must first stop the fighting and then try to solve peacefully the crisis which caused it. The peoples of the world and public opinion have a critical weight in determining whether right, justice and freedom will be respected everywhere in the world. It is important to remember that it was world opinion which was in large part responsible for the liberation of the hostages held in Iraq lastNovember and December. And it is again public opinion which must forcefully state that the weapons must be silenced in order to allow negotiations and to begin to bring solutions to the serious problems of the region. Problems of security, development and justice, liberty and democracy, of disarmament. Each of these deserves the sustained effort of the whole international community and firstly, of the United Nations. Time, patience, imagination, generosity and knowledge must serve to construct and not to destroy.

Inspired by our duty of reason and civilization, our duty as human beings, we call on all our scientific colleagues in France, and beyond, on all our colleagues in other countries, especially our American, Arabs, Israeli, and European friends, to start to work with us right away to set up a long chain of peace and to ask our governments to make all attempts to stop the war and start negotiating.