whereby deductions are allowed for oil and gas exploration and development up to full cost plus two-thirds. I would urge that similar treatment be considered for R & D programs for new energy sources. Partnerships and cooperative ventures will work best, however, if they fall under clear, consistent, dependable governmental policies. We all need to know what the ground rules will be.

Conclusions

It is clear that the chemical industry should stop lamenting the decline of research and put more resources into it; not merely into projects promising to pay out in a decade or so, important as those are, but also into projects which will pay out after most of us are gone from the scene.

Some of this research can be done in industry and contract laboratories; much of it fits more logically into the universities. Wherever it is done, the important thing is that the work be given a wide range, and not be pointed only at obvious targets.

More research should be done that might have a bearing on chemical feedstock needs in the next century. Some examples would be basic research on the structure and chemistry of coal and research to help take the pressure off petroleum and coal as energy stocks—through fusion power and large-scale conversion of solar energy to electricity.

The only prediction it is safe to make about such projects is that the percentage of hits will be low and some people will be quick to criticize because the research is not relevant to current needs. All the same, this is a necessary type of investment, and the stakes are too high for the industry to be stingy. Basic research is not that expensive, and the nations of the world can afford to put a lot of eggs in a lot of baskets, and watch them all.

The generation in charge now can not in good conscience go on consuming the world's supply of hydrocarbons, and not acknowledge a duty to the generations that will follow. Thus we must work together across the boundaries of nations and institutions, through research, through development, and through education, to be responsible stewards of the raw materials at hand, and to create new resources for the future.

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NEWS AND COMMENT

Technology Creep and the Arms Race: Two Future Arms Control Problems

This is the last of three articles about the impact of technology on the arms race.

Military policy debates in the United States have usually revolved around perceived major dislocations in the U.S.-Soviet balance—often around some supposed new threat to U.S. forces and the question of whether to deploy a big, expensive weapon system in response. In fact, this preoccupation with major decision points has inspired an entire literature perpetrating the view that the arms race escalates through a set of well-defined steps, up which the leaders of the United States and the Soviet Union deliberately tread.

Overlooked in the cliché, however, is the possibility that the arms escalator moves upward of its own accord, too. In the vast majority of U.S. military programs, which are neither very new nor very large, lower level bureaucrats, project managers and engineers, and systems commanders are constantly trying to find ways to make their weapons systems better. And this cumulative pressure for change can sometimes transform the capabilities of a system in unexpected or dramatic ways. Finally, both political leaders and the public often are unaware of this process of technology creep, or its implications in any particular case.

Another contrast between the notion of the arms staircase and that of technology creep is the question of motive. In the conventional view, political leaders make deliberate decisions to escalate the race, and thus by the same logic have the option to step down, or deescalate. But the race may be propelled as much by a few good or evil decisions as by human nature in general: it is hard to imagine the scientist who will not advertise the implications of his work, or the project engineer loath to incorporate improvements, or the military planning officer who does not want a system to work more smoothly, accurately, or faster.

As Herbert F. York, a former director of Lawrence Livermore Laboratory and a previous director of Pentagon research, has written of the U.S. contribution to the arms race, "The root of the problem has not been maliciousness but rather a sort of technological exuberance that has overwhelmed other factors."

The most urgent current example of technology creep is the gradual improvement in intercontinental ballistic missile (ICBM) accuracy over the last decade, which promises to bring the missile forces of both the United States and the Soviet Union to the point of having a destabilizing first-strike capability in the 1980's. This problem has become the touchstone for a major national debate over the future of the U.S. land-based missile force, and was the subject of the first two articles in this series (*Science*, 22 September, p. 1102, and 29 September, p. 1192).

There are two other, less well known cases of technology creep that may become the subjects of future national debates. One is the work in ballistic missile defense and antisatellite systems, which could make antiballistic missile (ABM) defense seem practical and could spark pressure to change the 1972 treaty by which the United States and the Soviet Union renounced virtually all deployment of ABM systems. The second case is arising from modernization of U.S. space satellites. Modernization is turning these peaceful systems into both peace and wartime tools and perhaps is the incentive for the Soviet antisatellite drive. Modernization of space technology may be fueling the very arms race that U.S. policy has tried to avoid.

The military programs from which these capabilities spring are not necessarily expensive. They are programs that the public decided long ago were desirable. None has had much publicity lately, partly because of a widespread belief that nothing has changed. So these pro-

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grams, while appearing to maintain the status quo, are actually moving toward important new capabilities.

U.S. plans to build an ABM system in the late 1960's were defeated, ultimately, on two grounds. One was that the Army wanted to defend both U.S. cities and missile sites from ICBM attack, and this was viewed as increasing the incentive to try a first strike and therefore as destabilizing. Equally weighty was the argument of many prominent scientists who had consulted with the Defense Department that the system simply would not work. The contention that it was unworkable succeeded not only in defeating the proposed U.S. ABM system but in prompting the United States to move for, and both sides to agree to, a mutual ABM ban as part of the May 1972 Strategic Arms Limitation Talks (SALT) accords.

Since the treaty reduced some of the risk of nuclear war, it is often hailed as a major escalating step in the arms race that the leaders of both sides wisely opted not to take. Under the treaty, both U.S. and Soviet ABM activities were limited to R & D work: also tests of other systems "in an ABM mode" were prohibited.

But ABM technology has not stayed within the neat confines of the R & D clause to which it was relegated. Tantalizing new methods of intercepting an ICBM attack are emerging not only from the Army's truncated ABM program, the Ballistic Missile Defense (BMD) program, but from the Air Force's separate program to develop antisatellite technology (ASAT). This is not surprising since the two problems are the same: Can one bullet hit another bullet in the vast reaches of space? The problem has three requirements: a tracking system to find the tiny object in space, some software to identify it correctly, and an interceptor to destroy it.

In the late 1960's the Army proposed to solve the first part of the problem with huge radars spaced around the country. But they were criticized because the cross sections of distant objects then available were not refined enough to discriminate between the incoming warhead and broken missile fragments, chaff, and decoys that could also be reentering the atmosphere. Moreover, the radars themselves were inviting targets because of their huge size and importance to the entire ABM system.

But sensing technology has come a long way since 1968: the BMD program is looking into long-wave infrared sensors that might sense temperature differences between the warhead and accompanying debris and could serve as an adjunct to regular radar. At the Kwajalein test range in the Pacific, the BMD program is testing a laser radar, or ladar, which, according to the government's arms control impact statement, is "inherently more accurate, may be smaller in size and weight, and less susceptible to electronic countermeasures" than ordinary radar.

Another technique that is being sought for the ASAT program, which also has applications in basic astronomy, is adaptive optics. In this optical viewing system, a fixed mirror is replaced by either a mosaic of small mirrors or a single, deformable mirror. These are linked to a sensing system and computer, which constantly bends the mirror to correct for distortions in images produced by the atmosphere.

The self-correcting feature of adaptive optics also permits a system to correct for defects in the mirror itself—enabling cheaper mirrors to be used. The resolutions attainable by adaptive optics are said to be limited only by light diffraction.

In the late 1960's, Army ABM planners proposed that a single computer could mastermind the incoming radar data, decide which objects were warheads, and orchestrate the launch of a national system of interceptor missiles to counterattack. But critics charged that the computer would become a target itself and could become confused in the

Cattle Virus Escapes from a P4 Lab

An outbreak of foot-and-mouth disease was diagnosed on 15 September among cattle on Plum Island, site of the only laboratory in the United States allowed to handle the virus. The outbreak has so far been contained without its spreading to neighboring Long Island. A study is still in progress to ascertain how the virus escaped from the high-security laboratory which is rated a "P4" containment facility equivalent to the former biological warfare laboratories at Fort Detrick, Maryland.

Foot-and-mouth disease, a dreaded and highly infectious malady of cattle and pigs, is usually combated by wholesale slaughter of all ill and exposed animals. The United States has been free of the disease since 1929. Last month the symptoms of foot-and-mouth were noticed in steers at a holding pen outside the main laboratories on Plum Island, a Department of Agriculture site devoted to study of animal diseases exotic to the United States.

When the disease was confirmed the following day, authorities dusted off an old emergency plan designed for such an occasion but never before needed. All employees save a skeleton crew were asked to leave behind their clothing and were sent home, off the island, in decontaminated coveralls and sneakers. The 30 or so infected steers were killed and hauled inside the laboratory for safe disposal of the carcasses. All other animals outside were slaughtered. The animal premises and all roads and vehicles on the island were sprayed with lye, and the office and cafeteria floors were treated with acetic acid. Meanwhile on the mainland, the Animal and Plant Health Inspection Service verified that the herds from which the infected animals had been purchased were not the source of the disease and that people from Plum Island were keeping away from domestic animals.

When decontamination procedures on Plum Island are completed, sentinel animals will be installed. If no signs of the disease develop, the island could be back to normal operation by mid-November.

"We feel very pleased about it. We have contained the virus, there has been no spread, and we think our steps are well planned," says Plum Island researcher Charles Campbell. The designers of the laboratory specified that it should be built on an island. "We are rather thankful for that," says Campbell.

It is not yet known how the virus eluded the elaborate precautions and physical equipment designed to contain it. The laboratory building where it was being handled is kept under negative pressure so that no air will leave except through filters. Solids are incinerated and sewage decontaminated; workers shower and change clothes on leaving. The fact that only one pen of animals was infected suggests mechanical transmission of the virus rather than a direct airborne route from the laboratory. Construction activity on the island may be involved in some way; the outbreak is the first since the laboratory was founded in 1954.—N.W.

course of the high-speed battle (the defense has 100 seconds or less to intercept the warhead before it reaches its target). But now the military research establishment has had a decade of experience with computers that take sensor data and command the firing of precision weapons. The revolution in microcircuitry has enabled future ABM software to be smaller and more dispersed; the BMD program is even researching a small, 1 cubic foot computer to be carried on the intercept missile. At a computing rate advertised as 100 million instructions per second, it could do the work of four of today's large, general-purpose computers.

A number of reputable people, most notably IBM's Richard Garwin, have proposed simple, low-technology means of achieving an ABM system to defend missile sites, such as the explosion of steel pellets in the face of the incoming missiles. But such is the "technological exuberance" of those charged with working on ABM that only very recently has the BMD program taken these suggestions seriously; a hefty part of the $200 million per year budget for the program has been spent on elaborate computer hardware and software.

The ABM proposals of the late 1960's had two controversial interceptor weapons; one would have a 5-megaton warhead, and the other would detonate something like a neutron bomb over the United States to defend it, ironically, against nuclear attack. Needless to say, this caused public relations problems that also helped kill the program. Today several nonnuclear interceptor weapons are being developed, among them the classified HIT vehicle which the Vought Corporation developed for the BMD program and has adapted for ASAT applications. The HIT has a single, long-wave infrared sensor that would help position the weapon in front of the warhead and keep it there. Its power system, a ring of rockets in tubes, enables it to maneuver to stay in front of the warhead so that the warhead will fly into it and have to be destroyed. One ABM advocate says that the HIT vehicle redefines the old, bullet-on-bullet ABM problem. "Now the question is whether a one-eyed goalie can stop a puck from entering a goal."

Very advanced versions of these technologies hold out the possibility of a space-based, *Star Wars*-style ABM for the late 1980's and 1990's. By the late 1980's, BMD experts say, distant early warning satellites might be so refined that their information on attacking ICBM trajectories could be fed to a ground-based ABM to enable it to intercept the ICBM's midway through their flight. In the 1990's, these early warning satellites could be linked to space-based laser or beam weapons, to attack the ICBM's during the earlier, boost phase of their flight.

So, the evolution of technology may give U.S. political leaders a second chance to step up or down the arms staircase through policy decisions on ABM. George Rathjens, one of the prominent foes of the 1968 ABM proposal and coauthor of an important book on ABM, believes that as soon as these technologies produce an ABM system that appears feasible, there will be instantaneous, strong pressure to modify or abrogate the 1972 treaty and deploy a system. "Let's be blunt about it," Rathjens told *Science*. "If ABM had been attractive technically, we never would have gotten the treaty."

ABM experts believe that the ABM debates of the future will take place on two levels. The first, immediate, debate will be whether a practical ABM could be built in the early or mid-1980's to defend U.S. land-based ICBM's against attack by lethally accurate Soviet missiles. They believe that the public, turned off by the $30 billion Air Force solution to ICBM vulnerability (which consists of a new ICBM system), may choose the lesser of two evils and vote to modify the treaty to allow cheap, missile site defense instead.

On the second level, later in time, an ABM debate could erupt because some combination of early warning sensors and satellite-based weapons could be advertised by the military as a feasible, space-based ABM. This debate could be more complicated and could become a rerun of the one that took place in 1969. For such a system would try to intercept all ICBM's, both those attacking cities and those attacking missile systems, and so would raise what one defense official calls the "canonical" question of whether blanket protection from nuclear attack is desirable. Also, as in the 1969 debate, a space-based ABM might be criticized on the grounds that it, too, will not work. So history may come full circle, and once again the question of banning ABM may come to turn on whether the hardware itself makes sense.

An Arms Race in Space?

If ABM is a case of technology creeping around the confines of an arms control treaty, and wriggling through the door of the treaty's R & D clause, then space surveillance offers a case where gradual modernization threatens to outrun arms control understandings. As with the ABM of the 1960's, the prospect of fighting a war from or in space has not been technically feasible in the past. Therefore, U.S. arms control policy has been to try for a mutual understanding that weapons should be banned in space. However, it is questionable whether the Soviets ever shared in this understanding, especially in view of their tests of an alleged "killer" satellite system, which they resumed in 1976. The United States seeks to have satellite interceptor tests banned in the arms control talks with the Soviet Union under way in Helsinki.

Vague understandings aside, the legal bans actually negotiated during the last decade and a half have been spotty indeed. The 1963 atmospheric test ban treaty prohibits the testing of nuclear weapons in space. The 1967 outer space treaty prohibits stationing nuclear or other "weapons of mass destruction" in space, and adds that there shall be no weapons of any kind on celestial bodies. It thus prohibits men on the moon from carrying guns, but begs the question of whether nonnuclear exotic systems such as laser or beam weapons fall under the ban. Finally, the 1972 SALT accords included an agreement that neither side would "interfere" with each other's "national technical means of verification," the euphemism used to signal space reconnaissance systems.

But none of this language prohibits the development of space systems which assist in the conduct of war, or of antisatellite systems designed to shoot them down in war. Both developments are taking place, promising a radically different picture of future space activities.

For instance, one reason that satellites have been viewed as peaceful is that they do not send their data to earth instantaneously. In the early 1960's, 2 weeks elapsed between the time a Soviet activity on the ground was photographed by U.S. satellite cameras and the time it was first seen on film by Central Intelligence Agency analysts. Now some communications and photoreconnaissance satellites operate in real time, but the others have lags of hours, days, or weeks. Modernization will make almost all space surveillance take place in real time, thus offering valuable military intelligence for commanders in war.

Some reconnaissance satellites, for example, may use return beam vidicon (RBV) television scanners, which are better than but similar to the civilian Landsat satellites. The RBV achieves real-time transmission by sacrificing high resolution; they have geometric distortions and a built-in lag between the time the scanner can re-record a given scene. Finally, they are bulky and expensive.

But an offshoot of the silicon chip electronics revolution, called charge-coupled devices (CCD's), that has already produced cheap, lightweight, high-quality television cameras for commercial use, is producing military high-resolution "stare" cameras that can be built either for visible light or the infrared, and offer high resolution and little geometric distortion. Mosaics of CCD's, each transmitting analog data in real time, can also be designed to process some of the scene—thus simplifying the problems of earth-bound intelligence analysts.

CCD's have been hailed as bringing about major advances in the quality of photo- and infrared reconnaissance. Sophisticated CCD early warning systems, for instance, could enable U.S. satellites to watch a nuclear war take place and tell ground commanders which silos had launched, which missiles had failed, and where each functioning missile was headed. (The Department of Defense, typically, gives this capability the name "attack assessment" and makes nuclear war sound like a bus service by calling it the "trans-attack.")

Besides enabling real-time surveillance, modernization is removing other obstacles to thorough intelligence gathering. The problem of cloud cover, for instance, is being solved. Space systems have been regarded as harmless partly because clouds and bad weather offered each side a shield against the snooping cameras of the other side. The Soviet Union has in the past mounted radar on board ocean surveillance satellites, presumably in order to track U.S. vessel movements in any weather. Because the Soviets operated only two such satellites at any given time, thus obtaining very incomplete coverage, and because the last such satellite, Cosmos 954, crashed in Canada earlier this year, this Soviet capability has not been viewed as much of a threat. But it shows the potential for more complete radar surveillance to locate enemy ship convoys in wartime and feed the data in real time to naval commanders seeking to attack.

Reconnaissance could become still more intrusive if high-resolution radars large enough to monitor large areas at a time were put into space. Defense Department witnesses have said that the high-resolution phased array radars, developed for aircraft use in conventional warfare, could be put in orbit by the U.S. space shuttle. Such surveillance would illustrate the double-edged quality that space systems seem on the verge of acquiring. While its ability to see through the clouds could help the United States verify a future troop reduction agreement with the Soviet Union, it could also be crucial in monitoring troop, tank, and aircraft movements over the European landscape in an actual war.

The new navigation satellites, the Navstar Global Positioning System, promise to play a similar double role. Both the 24-satellite Navstar and the existing 5-satellite Transit system it will replace in the 1980's are used by military and commercial vehicles to locate their positions. Navstar will be a more effective peacetime tool than Transit has been because it will be dramatically more accurate: Transit gives position to within 300 feet and Navstar will do so to within 30 feet. But during a war, Navstar could be very valuable for the accurate placement of ships, aircraft, and weapons equipped with suitable receivers.

A final "improvement" in space capability is the U.S. effort to harden its satellites against attack. This means that the traditional fragility of spacecraft, long a reason why they have been viewed as peaceful, is eroding.

Obviously, these changes in hardening, in completeness of reconnaissance, and in real-time data relay will make spacecraft more tempting military targets. They will also provide justifications for both sides' vigorous antisatellite programs. Charles Sheldon of the Congressional Research Service, who is one of the government's authorities on the U.S. and Soviet space programs, says of the new technology, "The old policies and concepts at the very least have to be reexamined, because in the end national states are going to do what they think is necessary for their own survival." In space, then, what started as "technological exuberance" to modernize may be fueling a brand new arms race and causing the abandonment of a long-sought U.S. disarmament goal.

Real Decisions Are Rare

In conclusion, it should also be said that there is another side to the entire issue of technology creep: it can produce stabilizing as well as destabilizing military developments. The most prominent historical example is that in 1960, at the time the Soviet Union shot down Francis Gary Powers' U-2 spy plane, and with it the notion that airborne reconnaissance was acceptable, several technologies had evolved to the point where satellite reconnaissance was feasible: the first successful test of the recovery of photographic film from space was made within months of the Powers incident. And with that successful recovery was born the era of peaceful space reconnaissance, which in turn formed the linchpin for subsequent arms control efforts.

A second example of good technology creep is the way the accumulated developments of 20 years have enabled U.S. missile-carrying submarines to operate in ever-larger areas of the ocean, thus staying well beyond the range of Soviet detection and keeping the nuclear deterrent secure. Nuclear power, multistage rockets, new propellants and lightweight motor casings, and now, very low frequency systems that enable the submarines to communicate at lower depths have all contributed to this stability.

Indeed, the encouragement of such technical evolution in both new and existing weapons programs is a fundamental goal of government science policy. And it is no small feather in science's cap that the "technological exuberance" U.S. science policies encourage can sometimes, either by design or serendipity, produce brilliant new combinations that contribute to world peace.

But it should also be no surprise that both "good" and "bad" technical developments are hopelessly intermixed, are offshoots of one another, and in cases such as radar reconnaissance through clouds, are sometimes one and the same development. So technology can neither be blamed for military problems nor extolled as a universal cure-all.

Instead, what seems to happen is that the ebb and flow of technical development goes largely unwatched by policymakers. When, as often happens, such developments change the capabilities of weapons, military doctrine can be slow to catch up. And as MIT weapons expert Kosta Tsipis has written, arms control policy adapts even more slowly:

> We have been witnessing a rapid transition to a new technological era that . . . provides opportunities for the development . . . of entirely novel classes of weapons systems.
>
> These weapons may very well not fit into the traditional categories of strategic or tactical, nuclear or conventional, Earth-based or space-based. Such categorization, however, has formed the conceptual framework of current arms limitation negotiating strategies.

So the conventional view of how military policy is made seems incomplete. Only rarely are political leaders handed genuine choices as to whether to escalate or deescalate the arms race, such as the ABM issue of the late 1960's. And even then, their options are determined by trends in military technology that have already been guided by lower level engineers and project managers.

So those who would look for ways to increase the country's strength, as well as those seeking new handles to arrest the arms race, might look to the fine structure of how weapons evolve, to find some answers.—DEBORAH SHAPLEY