Technology Creep and the Arms Race: ICBM Problem a Sleeper

In three articles, Science *will discuss how the creep of technology affects the arms race. The first two articles will deal with the most important current example: first, how ICBM modernization is giving both sides a destabilizing, first-strike capability, and second, how arms control seems to be dealing inadequately with this pressing problem. The third article will describe other cases of incremental technical improvements affecting arms control, such as antisatellite research and ballistic missile defense research, which are bringing both sides closer to the antiballistic missile capability they forswore in a 1972 treaty.*

Washington is gearing up for a major debate on the future of U.S.-Soviet relations and on whether the United States should agree to a proposed new Strategic Arms Limitation Talks (SALT) agreement with the Soviet Union. The agreement is expected to be sent to the Senate for approval in coming months.

A key part of this debate is the widespread belief that unless something is done about it, through SALT or by other means, the military balance of power between the two countries could shift in the next 5 to 7 years. This is because the Soviet Union is catching up with the United States in a crucial determinant of military strength, the accuracy of its intercontinental missile forces.

A remarkable number of disparate groups, who are often at odds on security issues, believe that by the early to middle 1980's the Soviet land-based intercontinental ballistic missile (ICBM) force will be able, at least in theory and perhaps in reality, to destroy 90 percent of the U.S. land-based missile force in a preemptive strike. This ability will primarily come from improvements in the accuracy of the missiles themselves. And the import of this ability—whether theoretical or practical—is that if Soviet leaders *think* they can destroy the U.S. land-based ICBM's, in a tense situation they might try it.

U.S. leaders have said that this prospect is politically and militarily unacceptable to the United States, despite the fact that our ICBM's are very accurate and now have, or will soon have, the ability to destroy the Soviet Union's land-based force in a first strike too. The United States has acquired this capability—which the Soviets might well perceive as threatening—despite the official U.S. doctrine that the United States would virtually never strike first. The policy of this country since the early 1960's has been that U.S. land-based missiles would ride out a Soviet attack, and those that survived, as well as the U.S. nuclear armed submarine and bomber forces, would retaliate by wreaking massive and assured destruction on Soviet society and industry. The doctrine is that U.S. forces exist to deter a nuclear war rather than to fight one and win it.

Since the mid-1970's, U.S. doctrine has also allowed for the possibility of some limited nuclear warfighting. This was the doctrine of surgically precise "counterforce" ICBM strikes introduced by former Defense Secretary James Schlesinger. But experts say that Schlesinger's shift in policy closed the barn door after the horse: it happened to justify the capability for surgically precise strikes that U.S. ICBM's were already well on the road to acquiring.

On the Soviet side, technological capability has not been congruent with doctrine either. For years the Soviet military doctrine has been that its ICBM force exists to deny its enemies the ability to attack the Soviet Union—that is, to knock out the military forces of China and the United States and so deny them the means to attack. But the Soviet military has been saying this for more than 15 years, despite the fact that its forces have not had this capability.

Then how has each side come to acquire the first-strike accuracy that the other perceives as so threatening, when in at least one case official doctrine discourages this capability?

What has happened is that the creep of technology—of the different technologies that bear on ICBM accuracy—has been advancing incrementally, cheaply, and with little public awareness, and so has landed the two superpowers in their current fix. Such marginal changes seem to have slipped through the cracks in past arms control negotiations, as negotiators have been preoccupied with limiting big items of hardware: the antiballistic missile system (ABM), submarines, bombers, and ICBM's themselves. But while focusing on the big, conspicuous, expensive, easy-to-count weapons, the policymakers have tended to allow R & D and the modernization of existing systems to continue. And the ICBM accuracy problem illustrates how, bit by bit, the creep of technology can transform the capabilities of a weapon system from one that contributes to stability to one that undermines it. So, in the tortoise-and-hare contest between technology and arms control, technology seems to be outwitting arms control and winning.

Missile accuracy is measured by the term circular error probable (CEP), which is the radius of a circle around the target within which 50 percent of the warheads aimed at it will hit. CEP's have declined steadily; the first U.S. ICBM's had a CEP of 5 miles, and the latest version of the Minuteman missile, Minuteman III, is believed to have a CEP of 750 feet (see chart). An older Soviet missile, for example, the SS-7, had a CEP of $1^{1}/_{2}$ nautical miles (approximately 9000 feet); and the most up-to-date Soviet ICBM, the SS-19, is believed to have a CEP of 1200 feet.

A recent *Christian Science Monitor* article stated that in recent tests the Soviet Union achieved a CEP of 600 feet, but this has not been officially confirmed. However, it is known that the belief in Washington that the Soviets will be able to achieve very good accuracies is based largely on recent intelligence on SS-18 tests. The Soviets are also developing a new generation of ICBM's.

The threat that past and current ICBM's have posed to the other side's land-based ICBM force has varied with the yield of the attacking warhead and the hardness, or resistance to nuclear effects, of the target silos. Experts agree, however, that as CEP's become smaller, yield and hardness become less important, because the target silo will be contained in the crater made by the explosion of the attacking warhead, and so will be destroyed. For instance, in missile silo damage calculations published by MIT physicist and weapons expert Kosta Tsipis, the silos are virtually certain to be destroyed when CEP's drop into the 500- to 50-foot range. At these low CEP's ICBM's can be said to have "absolute" accuracy because the certainty of destroying the target has become so large.

Missile guidance experts have predicted for years that the achievement of these absolute accuracies is a matter of simple technological evolution. In 1970, David Hoag, a leading engineer at the Charles S. Draper Laboratory, which developed inertial guidance for U.S. missiles and the Apollo program, predicted that "present technology is easily capable of achieving" 90-foot CEP's. Hoag's paper and other authoritative documents, such as the testimony of the long-term director of space and strategic research for the Pentagon, John B. Walsh, have described how gradual improvements in a range of technical areas will bring about these accuracies.

Science has compiled a list of six technological fields whose development is contributing to the achievement of absolute accuracy by both U.S. and Soviet ICBM forces. The list is anecdotal because detailed applications are classified and because public information about the Soviet program is almost nonexistent. It was compiled from interviews, from the official arms control impact statements filed with Congress this year, and from some technology "monitoring" files compiled by the Program in Science and Technology for International Security at MIT, whose associate director, Tsipis, has been studying the impact of technological advance on the arms race.

1) *Electronics*. The greatest aid to the accuracy of all weapons has been computer microminiaturization. Putting more logic, memory, and computational ability into very small spaces helps accuracy in at least two ways: the missile can obtain finer readings from guidance instruments, process them in a more complex manner, and give more sophisticated directions to the control system. This improves the likelihood that the reentry vehicle (RV) will reach its target by greatly increasing the number of course corrections it can make en route.

A second advantage is redundancy: backup "brains" can be installed for any particular system, increasing reliability and the confidence that the RV will reach its target.

The new electronics was the key to the development of multiple independently targeted reentry vehicles (MIRV's) in the early 1970's. A MIRVed missile carries 3 to 14 RV's aboard a "bus," which rolls to successive positions, discharging RV's that will take independent routes to different targets. With MIRV, a given force of ICBM's can attack a larger number of targets; MIRV therefore increases the odds of success of an ICBM attack. But the United States declined to ban MIRV's in the SALT I talks because of its early lead in technology; the Soviet Union first tested MIRV's in 1973 and is deploying them now (see story, p. 1112).

2) *Guidance and control*. The guidance and control system of an ICBM uses inertial navigation in order to be impervious to all outside forces. Inertial navigation was developed by the military, but it has been used in the space program and to tell commercial aircraft where they are, regardless of weather and changes in heading and velocity.

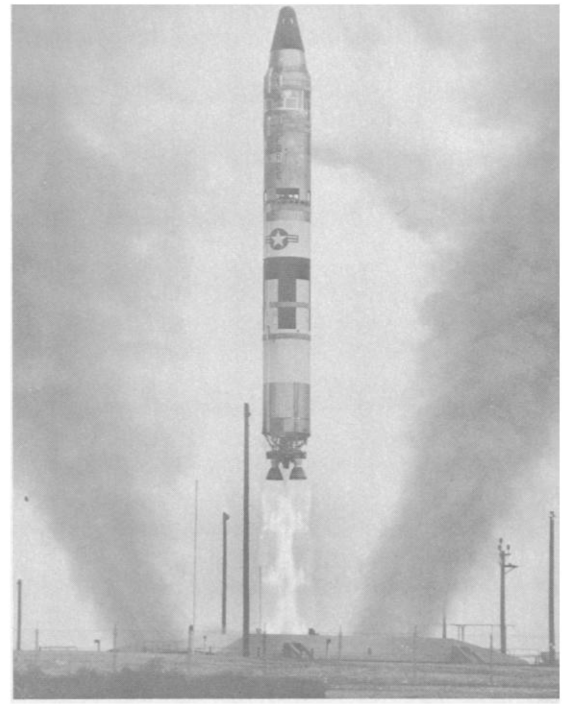
Inertial guidance has typically consisted of three high-precision gyroscopes on gimbaled platforms in mutually perpendicular directions. Each has an accelerometer on it measuring acceleration in that dimension. Computing machinery adds up the forces, adds in factors such as gravity, and so "knows" the system's position relative to that at launch.

Steady improvements in the mechanics of these systems have improved their accuracy. In one refinement, the ball bearings in the gyroscopes have been designed to spin continuously while floating in the air, instead of resting on a surface. This eliminates not only inaccuracies caused by warm-up of the system, but also errors caused by wear and the thermal effects of contact between the spinning bearing and the surface.

But mechanical systems can be improved only so far. One reason why the next generation of U.S. missiles, the land-based MX and submarine-launched Trident II, will be even more accurate than the Minuteman III will be a new floating ball inertial system, in which a single sphere measures the inertial forces in all three dimensions at once. The system is known as the advanced inertial reference sphere (AIRS).

(Knowledgeable sources believe that the Soviet Union uses a three-gimbal inertial system in the current generation of the SS-17, SS-18, and SS-19 missiles. They also believe that mechanical improvements have been responsible for increasing the accuracy of these missiles.)

Considering technology creep as a factor in the arms race sheds light on export policy. A case in point was the export of some relatively cheap, precision ball bearing grinders by the United States to the Soviet Union in 1972, during a crucial period in the Soviet MIRV program. Bryant Grinders Inc., a Vermont company, for years made the best precision ball bearing grinders in the world. After seeking to import Bryant grinders for many years, the Soviets were allowed to place an order in 1972 because comparable Swiss and Italian ones were available. The resulting shipments in 1973 and 1974 were accused of aiding the Soviet MIRV.



Launch of a Titan II ICBM from a test silo, 1963. [Photo: U.S. Air Force]

3) *Knowing where you are: gravity, geodesy, and global positioning*. During most of its flight, an ICBM is in a free-fall ballistic trajectory well above the atmosphere. Since gravity is the principal force acting on it, the better the knowledge of the earth's gravitational shape, or geoid, the more accurately can the free-fall stage be planned. Defense official Walsh, in testimony before a House subcommittee in 1976, said that the reduction of errors due to gravity and geodesy is being "supported by all the research the whole world is doing in the field of gravity," and civilian research in geophysics and geodetics obviously plays an important role.

In the early 1970's, Walsh said, the United States reduced the error due to these factors in several successive stages. This was probably assisted by geodetic satellites the military flies over ICBM trajectories. The Soviet Union also flew a series of circular-orbiting geodetic satellites between 1972 and 1975, according to an authoritative Congressional Research Service report.

Refined models of the missile flight path, based in part on improved gravity models, helped dramatically cut the CEP of the Minuteman III RV's in 1978, when the software programs for all 550 missiles were changed to an inconspicuous program labeled NS-20 guidance improvements. The cost of actually implementing this change, which reduced CEP's from 1200 to 750 feet, was a mere $4 million, according to the arms control impact statements released by Congress.

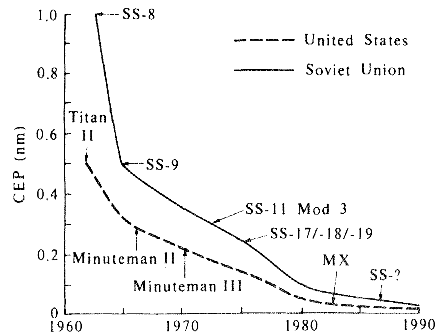
ICBM's in flight are not the only things that need to know more precisely where they are, and a spin-off civilian-military satellite navigation system, called Navstar, will make submarine-launched missiles more accurate. The Navy's current satellite navigation system, Transit, locates ships and aircraft within 180 to 390 feet, but its successor, called the Navstar global positioning system, will enable a user to "determine his position to better than 10 meters accuracy, velocity to a few centimeters per second in three dimensions, anywhere in the world, at any time, regardless of weather conditions. . . . Precise time would be available . . . accurate to fractions of a microsecond," says the impact statement.

U.S. strategic missiles could not rely on Navstar because in a nuclear war the Soviet Union might disable the satellites. One exception will be submarine-launched missiles. The ICBM-carrying submarines will use Navstar in the 1980's to obtain position fixes when they come to the surface.

In fact, one important result of technology creep is that submarine-launched missiles are becoming counterforce weapons, contrary to official doctrine, which says that they are to be used against big, "soft" targets like cities. But because of the cumulative effect of many small changes, the Trident II sub-launched missile, planned for the 1980's, could achieve absolute accuracy. It could do this through (i) better position fixes by the submarine using Navstar; (ii) improved submarine inertial guidance; (iii) better computers on the missile itself; (iv) AIRS guidance; and (v) stellar navigation and/or terminal homing.

4) *Sensors*. New sensing systems are enhancing the value of onboard small computers and vice versa. There are many kinds of sensors—they can be based on infrared, radar, terrain matching, laser, or electro-optical principles—and they have diverse military applications. After all, few of the problems of gathering intelligence or fighting a war could not be alleviated with the addition of "eyes" to sense what is going on and an accompanying, specialized "brain" to process these data.

In the ICBM field, sensors will play the largest role when missiles are equipped with terminal homing devices. This will happen probably as part of a modernization of MIRV called MARV (for maneuvering reentry vehicle). In a MARVed missile, not only will the bus that fires individual RV's have a guidance system, but the RV's themselves will have their own little guidance systems. With the addition of radar and other sensors that can search for the target and computers to aim the RV toward the



Improving accuracy of U.S. and Soviet missiles. By the mid-1980's both sides will have CEP's of 0.1 nautical miles or 600 feet. [Source: Colin S. Gray, "The Future of Land-Based Missile Forces," Adelphi Paper No. 140, Winter 1977, p. 5 (I.I.S.S., London)]

target, the CEP's of MARV warheads will fall to essentially zero.

Cruise missiles, which are in some ways true innovations because they can replace the manned bomber as a retaliatory, second-strike weapon, are also the product of technology creep. The sensing system that enables them to find their way over land, hugging the ground below the radar horizon, is a terrain-matching system now called Tercom, for which a patent was filed in 1959. The original purpose of Tercom was to aid in the navigation of ships and airplanes, and it was not until Tercom was married to the small new engines invented in the late 1960's that the resulting device began to have revolutionary implications.

5) *Engines*. The long-range cruise missile, which is really the only "new" strategic nuclear weapon in the U.S. arsenal, is partly the product of new small-engine technology that is causing small, remotely piloted vehicles of many kinds to proliferate. The cruise missile turbofan engine developed from a research program in the 1960's that was trying to find a backpack-style engine which would propel a Marine short distances above the jungles of Vietnam. The engine, developed by the Williams Corporation, is one of several that took engine design out of the heavy-machinery category and that use newer, lightweight, short-lived, but high strength materials.

6) *Materials*. Many advances in materials in the civilian commercial sector have helped the development of ICBM's. The best-known example is Kevlar, a material stronger than fiberglass that Dupont developed for radial tires. Years later, in 1972, some defense contractors spotted a Kevlar display at an aerospace fair on the West Coast and realized that it was an ideal lightweight casing material for the high-burning propellant planned for Trident I. Kevlar 49, a variant of the radial tire material, is now used in the Trident program.

Some materials advances have contributed directly to missile accuracy. In the late 1960's the United States used compound epoxy resin as the heat-shielding material on its missile nose cones. Later it was found that a ceramic burned more evenly in the very hot, unsteady conditions of reentering the atmosphere. A more even burn meant that the nose cone was less distorted in shape and kept to its course better during reentry. So the United States now uses a ceramic as heat-shielding material.

As further evidence that spin-offs from civilian research can aid technology creep, one of the companies that has worked on developing ceramics for missile nose cones is the Coors Porcelain Company, a part of the Coors beer empire in Denver. Coors Porcelain primarily makes ceramic valves for domestic uses such as auto engines and home faucet spigots.

Although experts say that the Soviets "are going down a similar curve" in reducing missile accuracy gradually through improvements on a range of fronts, they also note that the Soviet ICBM program is far from a mirror image of the U.S. one.

Experts tend to agree with the conventional notion that Soviet technology lags far behind that of the United States. However, they note that in the missile program, the Soviets can compensate. For example, Soviet missiles and the payloads they carry are physically larger than their U.S. counterparts. This means that they have less need for microminiaturization in building the newer, more complex payloads, so the much-vaunted U.S. lead in microminiaturization may not be as great an advantage as it seems. "Because they started big they can now trade off," explains one source. In addition, the greater yield of Soviet weapons compared to U.S. ones compensates for their poorer accuracy to a large extent.

Onboard computers are also relatively new to the Soviet ICBM program. They were just introduced with the SS-19 missile. On the other hand, there may be slightly less need for midcourse computer-guided corrections in Soviet missiles, because they use liquid fuel propellants which are easier to turn off after lift-off and so may give a smoother ride.

But there is one element that the U.S. and Soviet missile modernization programs have in common, namely, that such modernization is greatly favored by the people who design, build, and operate the missiles themselves. Unlike truly innovative new programs, which can threaten roles, missions, and budgets, gradual improvements to existing systems do not encounter resistance in the military bureaucracy. If anything, they are welcomed. An example on the Soviet side is the odd fact that new Soviet missiles seem to be born as quadruplets. In the 1960's the Soviet Union deployed the SS-7, SS-8, SS-9, and SS-11 missiles; the 1970's generation are the SS-16, SS-17, SS-18, and SS-19 missiles. In the 1980's the Soviets plan to deploy another generation of four new missiles, according to some public remarks by Defense Secretary Harold Brown. Why always in fours? U.S. experts say that the organization that designs Soviet missiles has four separate design bureaus, and that each is allowed to design a new generation, once the current generation is off the drawing boards and deployed.

On the U.S. side, enthusiasm for ICBM improvements was illustrated in a series of articles in *Aviation Week* magazine in 1976, which discussed how a new Command Data Buffer system would improve the ability of the commander of a field of ten missiles in their silos to retarget the missiles. Whereas soldiers from the command center that operates the ten missiles previously had to deactivate the missiles and get in a truck and drive to the silo to retarget them, the new system made it possible to do this electronically in much less time. Probably reflecting Air Force enthusiasm for the improvement, the articles discussed the many conveniences of the new system, without mentioning its impact on overall U.S. ICBM capabilities. For, by enabling quick retargeting of U.S. missiles, the change enhanced the ability of the United States to fight out and try to win a nuclear war and moved the land-based ICBM force one step farther from the "mutual assured destruction" role that is official doctrine.

Another feature of the improvements listed above is that, by and large, they are relatively cheap, and so attract little attention from Congress and the arms control community, who monitor defense budgets as a way to find out about important developments. A case in point occurred when, having successfully obtained R & D money for the NS-20 guidance improvements, the Pentagon sought in the fiscal 1977 budget to obtain funds to implement the programming change that would reduce the Minuteman CEP down to 750 feet. When researchers for the Federation of American Scientists (FAS) tried to find evidence in the budget for this dramatic change, they could find no line item in the budget devoted to it: funds requested for the NS-20 guidance system procurement were merely $4 million. Although the FAS and other arms controllers opposed the implementation of this improvement, they did not succeed, perhaps because the changes were too cheap to alarm those congressmen concerned with cutting defense spending.

So the technology creep that is transforming U.S. and Soviet strategic missile accuracy has foiled not only arms controllers but perhaps official negotiators seeking more formal limits. The next article will discuss the present dilemma: whether the proposed SALT II treaty, the plans to redesign the land-based ICBM force to avoid a Soviet attack, and other policy options can resolve the resulting military and political problem.

—DEBORAH SHAPLEY

Defense Scientists Differ on Nuclear Stockpile Testing

A technical disagreement of considerable political moment has arisen publicly among defense scientists. The question is whether nuclear testing is essential to assure confidence in the reliability of the national stockpile of nuclear warheads. The answer could critically affect the prospects for a nuclear test ban treaty, which are now more promising than at any time in the last 25 years.

Long the Cinderella of arms accords, the comprehensive test ban could do more than any other treaty to place a technological brake on the arms race between the United States and the Soviet Union. The ban would also be a timely step toward preventing the proliferation of nuclear arms among other countries. On the other hand, it poses certain perceived risks for those responsible for maintaining and improving national nuclear stockpiles. The Soviet Union's desire to delay China's acquisition of nuclear knowledge may underlie Russian interest in a treaty. In a significant concession, the Russians last year agreed in principle to forego peaceful nuclear explosions.

President Carter responded on 20 May this year by instructing his negotiators to seek a 5-year comprehensive test ban with the Soviet Union. But the decision set off a round of bureaucratic in-fighting, with the Pentagon and the Department of Energy pushing for a treaty of 3-year duration along with a statement that testing would resume thereafter if a satisfactory permanent agreement had not been reached.

As part of the effort to persuade the President to reconsider, Secretary of Energy James Schlesinger, whose department supports the two nuclear weapons design laboratories, visited the White House on 15 June. He and the two laboratory directors, Harold Agnew of Los Alamos and Roger Batzel of Livermore, reportedly spent an hour and a half telling Carter of their objections.

Opponents of the proposed treaty were given a helping hand at hearings held on 15 August before the House Armed Services Committee. A staff member reportedly furnished a list of questions in advance to a Department of Defense witness but not to representatives of agencies supporting the President's position. The Pentagon representative betrayed his prior knowledge by reading out his answers to the supposedly spontaneous questions.

Another backscenes interagency brouha-ha at the hearings devolved about testimony given by the Department of Energy. All agencies were meant to share written testimony beforehand with a group known as the "backstopping committee." Ructions and ill-feeling were caused by the failure of the Department of Energy to do so. Donald Kerr, the department's Assistant Secretary for Defense Programs, says he had no prepared testimony to share; he spoke from notes and was in any case summarizing testimony given at a previous hearing in March.

In Moscow, Kerr's testimony is understood to have seemed sufficiently inconsistent with the Administration's position that the Russian negotiators at Geneva were instructed to inquire about its significance. Kerr's remarks also alarmed supporters of the test ban nearer home. His testimony seemed in general drift, if not in specific detail, to contradict the White House's expressed desire for a test ban accord. Without certain tests,

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