Economic and Technological Trends Affecting Nuclear Nonproliferation

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Nuclear proliferation, and consequently nuclear nonproliferation, is driven by politics, economics, and technology. Each of these factors exhibits trends of various types. This article discusses how these trends affect the motivations for nuclear proliferation and also influence the choice of recipe for nuclear proliferation; that is, what materials, source of materials, explosive device design, delivery method, concealment, and facility security measures are selected by a state seeking nuclear weapon capability.

This article begins by discussing the motivations of potential proliferant states and certain opposing trends that have helped slow proliferation in the past. It then examines emerging changes in such motivations that may stimulate additional proliferation in the future and the effects of several economic and technological trends that could erode existing barriers to proliferation. Next, it reviews possible responses to these disturbing trends, with special attention to counterproliferation measures, the military and political requirements necessary to pursue such efforts, and possible defensive measures that might be employed by a new proliferating state. Finally, the article offers a prospectus summarizing future proliferation and nonproliferation paths and provides recommendations for strengthening nonproliferation efforts.

Advocates of nuclear nonproliferation were dismayed by the Indian and Pakistani nuclear weapon tests in 1998.[1] However, testing of nuclear weapons from an existing but covert stockpile does not signify that any more proliferation has occurred. It simply changes the character from covert to overt. The amount of proliferation, however measured, has not changed. Neither the number of states proliferating, nor the degree of proliferation has changed. The implications remain the same. The lack of effective nonproliferation response following the testing, more than the actual testing itself, is likely to affect other states' motivations to proliferate.

It could be said that the positive and negative forces promoting nonproliferation have been successful in controlling proliferation up to this point in time. Some persistent, existing programs have not disappeared, although others have. Notably, South Africa, a successful autonomous proliferating state, chose to roll back its program. Additionally, the inheritors of nuclear weapons from the breakup of the former Soviet Union—Belarus, Ukraine, and Kazakhstan—also relinquished their programs. Most importantly, no new programs have appeared on the horizon for several years. This is a level of success, not failure; but it may not continue.

SECURITY AND POLITICAL FACTORS SUPPORTING NUCLEAR NONPROLIFERATION

The positive reasons that contributed to nonproliferation holding the line for many years include several circumstantial factors. One is a lack of motivation to acquire nuclear weapons on the part of those states that possessed the economic and technical capability to do so. Any possible benefits of proliferation are marginal if there is no security threat for a state and no potential use for such weapons. For most economically advanced states during the 1990s, boundary questions were long ago resolved, no aggressive intentions have been evident among neighbors, and little concern exists that any threats might arise. Large volumes of international trade have created economic links among the highly developed countries, which further reduces concern that a state might have about possible attacks.

In previous decades, the dominant security threat for most economically advanced states was bipolar, between the communist and non-communist groups of states. The United States and the Soviet Union, through bilateral treaties, extended a nuclear umbrella to most of the economically advanced states of their respective allied groups. These treaties provided for the defense of the given state in the case of a nuclear attack. Thus, there was little advantage from having an independent capability for nuclear weapons. Furthermore, the fear existed that the possession of nuclear weapons would increase the chance of being directly involved in a nuclear exchange between the Cold War's leading powers. Great Britain and France were the only states that did not adhere to this reasoning, perhaps for reasons of national prestige. Although these mutual defense treaties were initiated in the Cold War period, the surviving North Atlantic Treaty Organization (NATO) alliance and Russia's strong presence in Central Asia still provide some hedge against proliferation. However, it is not likely that these security guarantees will be extended more widely, as the bipolar structure of world alignment has broken down.

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) has also assisted in developing a global political environment that inhibits nuclear proliferation. The NPT allows states access to peaceful nuclear energy, which provided an original impetus to join. Moreover, states that signed the treaty have not only placed all of their nuclear activities under international monitoring, but have also, to some degree, created a nonproliferation culture. Portions of government administrations as well as popular and media groups have become involved with nonproliferation questions. In these states, a set of adherents to national renunciation of nuclear weapons developed over time. This is, of course, more true in states with a well-developed democratic tradition. There is also a large popular antipathy toward nuclear weapons present in many states, which tends to impress democratically elected leadership. With little security advantage to be gained and political disadvantages apparent, it is no surprise that the NPT has been widely adhered to and respected by states with advanced economies.

COUNTERVAILING MOTIVATIONS FOR NUCLEAR PROLIFERATION

It has also become clear that the motivations for nuclear proliferation have not disappeared completely. Overt testing by India and Pakistan brought their nuclear weapon programs into the international public sphere, and prominent figures in both states have discussed their motivations. These statements illuminate some of the reasons that lead states to proliferate.

K.C. Pant, the defense minister during India's 1974 test and head of the government committee that affirmed the plan to test in 1998, stated that India was opposed to the two-tier system of nuclear "haves" and "have-nots," which was reinforced by the 1995 unlimited extension of the NPT. He also criticized the perceived failure of the nuclear "haves" to fulfill their disarmament obligations under Article VI of the treaty.[2] International prestige was yet another stated reason for India's decision to go public with its nuclear capability. A former Indian Air Force chief of staff stated that India was not taken seriously by other states. In his view, becoming a nuclear power would rectify that and perhaps eventually lead to a permanent seat on the United Nations (U.N.) Security Council, which he felt India deserved on all counts.[3] However, proliferation for the purpose of prestige has rarely been publicly discussed by other states and may not be a common desire.

Security concerns formed an integral part of India's motivations. Jasjit Singh, Director of India's Institute for Defense Studies and Analyses, affirmed the view that the nuclear tests were necessary to demonstrate India's ability vis-à-vis the threat posed by China's nuclear weapons.[4] Indian Defense Minister Georges Fernandes spoke in more abstract terms about the benefits offered by nuclear weapons: they provide a deterrent, he stated, and allow states to take steps to advance their regional security interests that they might otherwise be reluctant to pursue.[5]

Justifications expressed by Pakistani commentators focused on the regional security threat posed by nuclear-armed India.[6] These security justifications are reminiscent of those of the Cold War, in which countries developing nuclear weapons do so out of fear of a nuclear attack by one of their nuclear-armed adversaries. In simple terms, these states desire a retaliation capability.

Although nuclear weapons in the hands of a larger power might not provide useful leverage against a smaller non-nuclear adversary (as the United States learned in Viet Nam and Russia learned in Chechnya), these weapons can increase freedom of action for major regional states such as India or Iran in dealing with non-nuclear regional challenges by discouraging intervention by more powerful outside states. Nuclear weapons can also enhance the security of smaller regional states that confront potentially overwhelming conventional threats from their neighbors. Israel has not made any definitive statements about the development of nuclear weapons, but the existing political situation in the Middle East leads to some obvious hypotheses. The possession of nuclear weapons by a state in Israel's position may deter the escalation of conventional war, and in particular, serve as a deterrent against invasion. South Africa, during its period of nuclear proliferation, apparently felt much the same.

Thus there are three potential motivations for the middle-sized states of the world to acquire nuclear arms: (1) to gain prestige; (2) to deter larger adversaries or groups of them; and (3) to accomplish internal or regional security tasks that might be otherwise be infeasible because of the prospect of intervention by more powerful, extra-regional states.

For a smaller state that might be attacked by larger powers or groups of them, nuclear weapons can be seen, in the modern arena of international relations, as analogous to the Colt .45 of the American West. The Colt .45, a type of pistol that was carried by a large number of western settlers, ranchers, and cowboys, changed the rules of engagement between individuals during the settlement of the western half of the United States. There was no rule of law established in these areas, and individuals were often forced to defend their rights or promote their individual welfare single-handedly. The Colt .45, at least in the popularized version of American history, changed the rules of conflict. Instead of battles being fought on the basis of brute strength or numbers, the Colt .45 gave weaker or outnumbered forces a chance. This weapon was easy to use, and speed and accuracy in firing—not strength—provided the advantage. Furthermore, as anyone seeking to overpower another did not simply risk injury but also death, the Colt .45 raised the stakes in the conflict. Furthermore, it increased the uncertainty of the outcome of any given conflict, which in itself served as a deterrent.

Nuclear weapons exist within a similar framework. If military force is employed to resolve a dispute between states, the state with an economic advantage or, alternatively, the support of allies, is often victorious. However, when nuclear weapons are present in the smaller country, the advantage of superior economic power pales, as the ability to defeat this nuclear-armed adversary is unclear. Nuclear weapons can be delivered by relatively simple technology, ranging from smugglers' boats and aircraft to primitive missiles. Their radius of destruction is large enough that pinpoint accuracy is not needed.

Additionally, nuclear weapons provide a means of raising the stakes of conflict. Given the possibility of nuclear weapon use, the conflict initiator must think long and hard about the possibility of the conflict escalating to the nuclear level. Decisionmakers must decide whether the benefits of their actions against another state are worth the potential consequences. In short, nuclear weapons provide deterrence against larger states and groups of states. Incidentally, deterrence does not necessarily go in the opposite direction; Argentina, for example, was not deterred by Great Britain's possession of nuclear weapons when it seized the Falkland Islands.[7]

Are there other states that might have the same perception of nuclear weapons as "equalizers" or deterrents against larger states or combination of states in both conventional and nuclear scenarios? The answer is "yes." Are there states that might feel that they have internal or regional security tasks that can be addressed by nuclear weapons? After the U.S. bombing of Serbian territory over the issue of Kosovo, many states may fear—rationally or irrationally—bombardment and dismemberment for policies they would rather have impunity to pursue. Even in Russia, the world's second nuclear power, some military experts feel that the Serbian precedent could also apply to Russia. For example, they fear that NATO may not hesitate to interfere with Russian actions in breakaway republics.[8]

For a state to consider a new nuclear weapon program as a solution to regional or internal security issues, the development of this capability would have to be possible in an acceptably short timeframe. Security issues may develop over a decade or less, and if a state perceived that a nuclear weapon program would post-date the threat it was meant to counter, it would be a poor option to consider.

ADDITIONAL FACTORS RESTRAINING NUCLEAR PROLIFERATION

Potential risks and costs dissuade states from proliferating. One factor is that proliferation produces physical risks to the proliferating state. These include the possibility of nuclear accidents at weapons facilities, environmental catastrophes, and the prospect that nuclear weapons or weapons-grade materials could fall into the wrong hands and be misused. The minimal history of such events indicates that these possibilities can be successfully contained, and it is not clear that a state with internal or regional security concerns would consider these possibilities important.

Another factor against proliferation has been the financial cost involved. The cost of nuclear materials and a weapons program is prohibitive for the smaller or less developed states of the world. Any state with a gross national product (GNP) significantly less than that of pre-war Iraq would be hard pressed to devote enough annual government funding to a nuclear weapon program to actually achieve positive results within a reasonable time, say 10 years. Iraq's GNP in the decade prior to the Gulf War was on the order of $100 billion in 1997.[9] Pakistan's GNP in 1998, when it tested its nuclear bomb, was on the same order.[10] During the 1980s when its nuclear program was active, South Africa's GNP was approximately one third of this.[11] To produce an initial cache of usable nuclear weapons might cost in the range of $1 billion to $10 billion,[12] which amounts to 0.1 to 1.0 percent of a $100 billion GNP over ten years. The exact cost of such a program depends on many factors; for example, the presence within the state of trained nuclear scientists and engineers as might be produced by an indigenous nuclear energy program. However, even with trained personnel present, the cost of the types of nuclear programs that have been used so far would not be feasible for economies significantly smaller than a $100 billion per year GNP.

This also interacts with timeframe issues. A proliferation program can produce results more quickly with more funding: however, if the cost is already very significant for the state, accelerating funding for it may not be feasible.

A third factor is the existence of controls on the technical expertise necessary to transform nuclear materials into explosive devices. To date, these controls have not been maintained to the same degree as those over nuclear materials. Training in nuclear physics and engineering continues to spread throughout the world, and the barrier that technical expertise plays is not likely to be the limiting one. Lack of expertise in leadership also plays a critical, but less discussed, role. Besides technical expertise, project management expertise in the scientific and technology sector is vital.[13] Nuclear proliferation programs can prosper or founder, depending on the quality of the technical management leadership. This type of expertise grows in states that have large, successful scientific research communities. Where this is lacking, however, major technical projects such as this have slower progress rates and lower probabilities of success. Yugoslavia's nuclear weapons program in the 1970s and 1980s may exemplify this, and the South American programs as well.[14] In some cases, technical project management expertise may compensate for the lack of specific technical expertise. For instance, management may decentralize the technical expertise needed and send staff members abroad to accumulate information in piecemeal fashion.

A fourth factor concerns the likelihood that international inspection or other sources may reveal a latent nuclear weapon program at an early stage in its progress. The International Atomic Energy Agency (IAEA) continues to improve controls on the diversion of nuclear material from nuclear fuel cycle programs. The IAEA is currently focusing on improving its inspection capability, making inspections more comprehensive and qualitative than in the past.[15] This improved capability, if brought to fruition, could further limit the possibility of maintaining a covert nuclear program.

A related issues are the possible consequences that would follow either the publich announcement of a nuclear weapon program or the accidental discovery of a covert program. These consequences could be either very minor or nonexistent, as happened with the Israeli and South

African programs (although South Africa had already dismantled its program when it revealed it). There may be mild or severe economic consequences in the case of the application of primary or secondary sanctions by either major or non-major trading partners, to say nothing of universal sanctions. The example of such sanctions on Iraq is well known. Diplomatic isolation may be another consequence, if relations were broken between the proliferating state and one or more major powers or close neighbors. The higher end of these possible consequences may be sufficient to deter states with the requisite economic resources.

Yet another, more severe, category of efforts to control proliferation is counterproliferation—i.e., the use of military measures to curb proliferation, including coercive rollback, where the military power of one or more states is employed to destroy the nuclear weapon capability of the proliferating state. The best known example of forced weapons of mass destruction (WMD) rollback is that of Iraq, which has faced this type of action twice thus far. First, in 1981, Israel launched a preventive attack on Iraq by bombing its Osirak reactor before it became operational. Then, in 1991, a multinational force led by the United States pushed Iraqi troops out of Kuwait, and, as part of the peace settlement, investigated and dismantled a clandestine nuclear program.

Such forced nonproliferation could certainly happen again, and the double example of Iraq must be a factor considered by any state contemplating proliferation. The U.S. aerial bombing of Libya in 1986 and missile attacks on the Sudan and Afghanistan in 1998 to destroy suspected chemical weapons factories also demonstrated the ability of a high-technology state to selectively demolish suspected WMD facilities. It is clear from the latest examples that strikes by aircraft are not necessary, and that precision missile attacks can accomplish the task of destroying targeted buildings. These missile strikes can be achieved at low cost to the attacker and with little international response other than diplomatic punishment, assuming the target country has no ability to retaliate against the attacker or its allies.

Thus the two most significant negative factors dissuading states from nuclear proliferation appear to be the cost of the program and the fear of discovery and military consequences. Below is a discussion of possible trends that may affect these restraints on proliferation.

ECONOMIC AND TECHNOLOGICAL TRENDS PROMOTING NUCLEAR PROLIFERATION

Continued worldwide economic growth has raised the GNP of many states. In the early part of the 21st century, some states may indeed be crossing the threshold where economic strength would allow the development of a nuclear weapon program without crippling their economy or conventional military forces, even if done rapidly. Military expenditures tend to be a fraction of GNP, and as GNP increases, so do available funds for a military nuclear program. Growth is, nonetheless, slow and gradual; for example, a three percent real growth rate in GNP or military expenditures only leads to a doubling in 24 years. Therefore, this effect is one that may span decades.

On the other hand, the cost of a proliferation program has been dropping markedly. The principal cost has been the production of nuclear materials; the cost of weapon development thus far has been a small fraction of the cost of a new program. However, new technologies have been developed to produce nuclear materials. Principal among these are the laser-based technologies, such as AVLIS (Atomic Vapor Laser Isotope Separation—in France, SILVA)[16] and SILEX, an Australian laser-based process involving molecular interactions, probably photo-dissociation, rather than the ionization of atoms that AVLIS uses.[17] AVLIS was developed to a commercial production level, and other laser-based technologies may also be pursued for commercial purposes. SILEX has replaced AVLIS as the process supported by the United States Energy Corporation (USEC), a privatization of U.S. nuclear materials production.[18] SILEX claims to be substantially cheaper than AVLIS to operate.[19] Many other laser-based techniques have been investigated as well, and may result in lower costs.[20] Other new, as of yet less developed technologies are likely to surface that may be used to produce nuclear materials besides laser isotope separation. For example, technologies are being developed based on accelerator-driven isotope production.[21] Because AVLIS is as of yet the most developed, it will be used as an example of how such processes affect proliferation.

One measure of operating cost is the amount of electricity needed to produce a certain amount of isotope separation. The development of gas centrifuges capable of isotopic separation dropped electrical costs for uranium isotopic separation considerably from gaseous diffusion.[22]

The first prototypes of AVLIS promised another significant reduction,[23] although the development of the process was halted in the United States before a full-scale production facility was built. There is the potential for significant further cost-reduction if high-power laser technology continues to improve and leads to more efficient lasers. AVLIS used high power dye lasers of low efficiency, pumped by higher power copper vapor lasers, to produce the laser beam that selectively ionized Uranium-235 (U-235), allowing it to be separated. These two types of lasers used a large part of the electrical power consumption of AVLIS technology, and improvements in laser efficiency will result in further reductions in energy requirements if AVLIS is reinvented in a proliferating state.

Furthermore, laser processes for isotopic separation may be done with much less capital expenditure. The total cost for 20 years of research and development to bring the AVLIS process to a commercial stage was estimated at $1.3 billion dollars.[24] Much of that time was spent in determining what types of components would be feasible. Since that has been done, and prototypes have been built, reconstructing the research elsewhere would be much faster, assuming the availability of adequate funding and technical personnel. Reconstruction can be much cheaper and quicker than initial, groundbreaking research and development, especially if adequate technical documentation is available to point the way. This means that the total expense for producing small quantities of nuclear material (i.e., kilograms per year) is much less with a laser method than with one of the older methods.

Experiments were performed using AVLIS equipment to enrich plutonium in the isotope best suited for nuclear weapons, Pu-239, and the tests were successful.[25] This means that if plutonium were separated from typical spent fuel, it could be converted in an AVLIS facility to weapons-grade plutonium, although the transformation is not essential. Typically, only low-burnup nuclear fuel from a special reactor, containing mostly Pu-239 and less other isotopes of plutonium, has been used to produce weapons-grade plutonium by chemical separation. This is no longer necessary if the AVLIS technology, or any other laser enrichment technique, is available for plutonium as well as uranium. Thus, a nuclear materials production facility based on laser methods might be both smaller and cheaper than with older methods and might allow the development of materials and weapons with nearly identical technology. This could, potentially, eliminate the need for a special reactor. AVLIS work was also pursued in South Africa for the production of lithium isotopes, used in thermonuclear weapons.[26]

Many claim that laser techniques are too complicated to be reproduced in a proliferating country.[27] The justifications for this belief are declining. Lasers, the key technology in laser separation techniques, are becoming more and more common in manufacturing, measurement, and other applications, and they are growing rapidly in capability. They may well be another "…ubiquitous technology that moves rapidly to ever-higher levels of capability," analogous to high-speed computer chips, which have proven to be uncontrollable by export control regulations.[28] As pointed out in 1999 by William Reinsch, U.S. Undersecretary of Commerce for Export Administration, controls on computers only served to develop stronger competitors abroad in states that were targeted for control.[29] This led to a possibly wider dissemination of the technology needed to produce them than might have occurred without these controls. Laser research and development does not require massive infrastructure and the high-power tunable lasers that are the key elements for laser separation methods will diffuse, much as has computing capability. The dye lasers and copper vapor lasers that were used for AVLIS are not the only technical solutions to generating the required light pulses. Free electron lasers (FEL) have also been used in experiments with isotopic separation.[30] This development could lead to more efficient and compact laser systems for laser separation methods; surely others will be developed.

TECHNICAL EXPERTISE AND PROGRAM MANAGEMENT

Another factor limiting nuclear proliferation, technical expertise (especially technical project management expertise), is affected by the trend of the globalization of economic progress. As manufacturing facilities disperse all over the world, project management expertise follows. The coupling of technical expertise from a general educational background and project management expertise from training on the job may result in the genesis of strong technical program managers in many more mid-sized states. Increases in technical project management skills could improve the chance of success and lower the probable cost of nuclear materials production, nuclear weapon design and development, as well as the design and development of delivery means.

EXPORT CONTROLS AS A BARRIER TO PROLIFERATION

One effective barrier to proliferation has been the imposition of controls on the export of equipment, materials, and technology critical to a proliferation program. Controls were initially set to bar the transfer of equipment and materials critical to the nuclear materials production methods that were thought feasible for a state bent on proliferation. In Iraq, the discovery of substantial progress in using an abandoned technique, electromagnetic separation, as an outflanking maneuver around export controls, led to the addition of export controls on this technique.[31] It is also quite possible that proliferation could proceed by outflanking the controls at the high technology end. Since laser isotopic separation methods involve technology more widely used than that of older methods, defining and enforcing effective export controls is more difficult. Furthermore, the smaller size of the equipment used in laser isotopic separation methods makes smuggling a potential option.

The era of isotopes has not yet arrived, where isotopically pure materials are used to enhance various physical characteristics, but some beginnings are visible. Isotopically pure carbon and silicon are used in semiconductors; lithium and gadolinium in nuclear power; and a number of other elements in medical technology and research.[32] The laser isotopic techniques useful for these materials have much in common with those useful for nuclear materials, which makes the task of export control much more difficult than with earlier methods of enrichment.

SANCTIONS AS A TOOL TO CONTROL PROLIFERATION

Economic growth has increased trade between states, and the combination of increased volume of trade and economic intertwining makes serious sanctions against a proliferating state less likely. It is quite clear from the example of Iraq that the growth and regeneration of a mid-sized state's economy can be prevented. Almost universal sanctions against Iraq have been in force for 10 years, and the Iraqi economy has recovered only slowly from the devastation caused by the Gulf War. After India's detonation of nuclear devices in 1998, however, sanctions were only ephemeral.[33] India is a major trading partner of many states, and the utility of sanctions in compelling an established nuclear power to relinquish its capability did not seem comparable with the economic costs that the sanctioning states would inflict on themselves. Though Pakistan's economy is less developed than India's, the same effect applies.

Another problem with employing sanctions to reverse successful nuclear proliferation after the first-test stage of a nuclear device is that they may provide incentive to the state to share its technology. In other words, if sanctions severe enough to cause a major economic impact are applied, internal pressure within the sanctioned country to allow or condone the spread of the technology that was used may mount. The result could manifest itself at the government-to-government level, but it might also appear at an individual level if, for example, a knowledgeable scientist emigrates. The threat of this form of migration from Russia and the other Newly Independent States (NIS) has been well appreciated, but it is also possible from new proliferating states. The technology used by such a state may be even more relevant to another state desiring to proliferate rapidly and inexpensively than that of a major nuclear power.

These negative possibilities imply that if a program is successfully concealed by an economically significant state for the period needed to produce the first round of nuclear weapons, Iraq-type sanctions are not the threat they might appear to be.

In sum, one by one, the barriers against proliferation are gradually falling, and for those states that anticipate continuing security challenges, there may be a strong temptation during the first decades of this century to proliferate.

DELIVERY AS A BARRIER TO PROLIFERATION

There is little point for a state to develop nuclear weapons if delivery systems for these weapons are beyond the state's capabilities. The preferred method for nuclear weapon delivery among the major powers has been ballistic missiles. There has been very extensive discussion of ballistic missile proliferation in conjunction with the U.S. interest in missile defense, and ballistic missiles have been studied in great detail. However, cruise missiles may be a more achievable delivery systems for many countries.[34] A cruise missile can be launched from a fishing boat or a freighter offshore and arrive virtually undetected at its target. Because cruise missiles are small and can travel at low altitude, ground-based radar systems have a very difficult time detecting them, and may not even provide enough warning time to enable the leadership of the target country to seek shelter.[35]

Cruise missile technology was used by the United States and its allies to bomb Iraq during the Gulf War. The utility of such missiles has clearly not been lost on the world's military planners, including those in mid-size states that might consider proliferation. The technology challenges involve mainly lightweight turbofan engines and guidance, and information about these is spreading. Turbofans power all modern large aircraft, and the technology to build lightweight versions for cruise missiles continues to disperse because of commercial availability and pressure. Williams International, the corporation that developed the Tomahawk cruise missile turbofan engine, has announced that it will be producing even smaller turbofan engines, the FJ2-X, for small aircraft.[36] This type of engine technology was first introduced around 1960 for drones and has been evolving and dispersing since then.

Guidance systems for cruise missiles could represent a significant barrier if low-altitude overland travel was required, but attacking a port city with a cruise missile is much less of a problem. So is higher-altitude flight. Simple inertial guidance or even Global Positioning System (GPS) control, together with an altitude sensor, would be sufficient for such an attack.[37] A cargo ship could in this case serve as a launch platform.[38]

Submarines also represent a possible nuclear cruise missile launch platform. Long-range non-nuclear submarine technology, air-independent propulsion (AIP), was developed in the late 1980s by Kockums Naval Systems in Sweden.[39] Submarines carrying liquid oxygen tanks and Stirling engines with electric generators were developed to avoid typically required surfacing and to reduce noise to a minimum. These features prolong the underwater travel distance to a few thousand kilometers (km). Without the need to surface and with no noisy nuclear reactor, conventionally powered submarines are very difficult to detect by any means. A submarine-launched nuclear cruise missile fired a few tens of km offshore would provide any state with a very serious military threat. These AIP submarines are now made by several states and are sold elsewhere. The French version is sold to Pakistan, which could gain sufficient technology to construct this type of submarine at its own naval shipyard and then sell it under license to third parties.[40] Pakistan already has the ability to launch a short-range cruise missile, the U.S. Harpoon, from torpedo tubes while the submarine is submersed . It will also be able to launch the French SM-39, the submerged-launch Exocet, from the new submarines.[41] These missiles are sea-skimmers and could be used to attack land targets. Boeing is now producing Block II Harpoons, which are land-attack versions that penetrate inland. The Harpoon carries a 250 kilogram (kg) payload, which may be enough for a first-generation nuclear warhead, and it travels over 100 km at near supersonic speeds. Russia also produces AIP submarines and is seeking customers, as is the German firm, Howaldtswerke-Deutsche Werft, which has merged with Sweden's Kockums.[42]

Nuclear smuggling has also been discussed as a delivery means, and there are variations for this type of scenario. Harbor or coastal cities are especially vulnerable to nuclear weapons carried in small ocean-going vessels. Small aircraft, difficult to detect with radar, may also be an option. Thus, difficulties in developing ballistic missiles are not likely to be a compelling reason for a state to forego nuclear proliferation. Even if these difficulties cannot be overcome, alternatives exist.

COERCIVE NUCLEAR ROLLBACK

These technological changes leave the fear of military intervention as one of the few remaining barriers to nuclear proliferation. One possible intervention is "coercive nuclear rollback." This involves enforced removal or destruction of a key component of a proliferation program, or the destruction of another component of economic life that can be used as a hostage in exchange for rollback. One method could be the bombing of facilities connected with a given state's nuclear weapon program, such as a plutonium-producing reactor, enrichment or reprocessing facilities, or laboratories involved in weapon-related research. A second example might be the gradual destruction of a country's energy infrastructure through bombing or sabotage. The selection of a particular type of forced rollback may depend on the balance between cost, the domestic political concurrence required, the potential risks, the possibility of convincing other partners to join the action, the ability to conceal the source of the actions, the likelihood of success, the precedent it might set, and the potential for unwelcome consequences, notably military retaliation against the attacker or one of its allies. The goals of a forced rollback program may be expressed in different ways, but they can be translated into achieving a period of delay of potential proliferation success. Any of these steps may result in permanent change, but since all are reversible over some period, time delays are a good measure of the effect of actions taken.

Forced rollback involving the lowest amount of violent action is the assassination of key individuals. The targets of such attempts may be either government leadership or those people possessing technical expertise or technical management capabilities who occupy critical roles. Actions against individuals, who may be easy targets, can be taken without overtly identifying the state involved.

Assassination of the head of a government may result in a political halt to the program, if the successor is less interested in proliferation. On the other hand, a successor may be more capable in accomplishing proliferation, and the assassination could thus spur weapons development. Furthermore, the assassination of top officials may be difficult to carry out. Assassinating a key individual within the program may set the program back a period of time until a replacement is found, and the time delay is dependent on how much information, such as technical expertise, was resident in that individual. Key technical individuals in a newly proliferating country, where abilities are scarce or irreplaceable, may be targets more likely to achieve the desired halt to proliferation activity.

Destruction of key equipment is yet another counterproliferation alternative, involving a slightly higher level of military activity. Many of the methods to build a nuclear weapon require specialized, controlled equipment that is difficult to manufacture or obtain. For a proliferation program based on the illegal acquisition of export-controlled items, the destruction of these components may halt a program and provide subsequent export controls a second chance at success. If the equipment's location is sufficiently well known, this can be achieved through bombing or by sabotage. The latter can be done without obvious involvement of the state performing or sponsoring it, while bombing is an activity more likely to implicate the responsible state.

The destruction can be directed instead to facilities dedicated to proliferation. This may involve the destruction of one or more buildings, or the elimination of a supply of controlled materials. The destruction of facilities can be accomplished by missile attack, airborne bombardment, surgical invasion by military forces, or sabotage by insiders.

Eliminating key equipment, materials, or facilities alone may result in some months or years of delay. If controlled materials or equipment are destroyed, and export control limitations foil replacement in the near term, substantial delay can result. Israel's bombing of Iraq's Osirak reactor slowed the proliferation process down and delayed Iraq's nuclear weapon development program by several years. It may also have strengthened Iraq's national resolve to proliferate and to develop better deception techniques. If a proliferation program is attacked by another state, and funding is tripled as a result, will this result in an overall delay in the completion of the program? In the case of the Osirak bombing, the exact nature of the reconstruction process that occurred in Iraq is not known. It is clear, however, that a lower-level attack may accelerate a program if the factors that drove the country to choose to proliferate are not ameliorated. Only where either the funding is a major strain on the state's budget, or where a program is dependent on external acquisition of controlled equipment, would there be an unmistakable advantage to bombing proliferation facilities, assuming the target country lacked the ability to retaliate, as was the case with Iraq in 1981.

Indirect methods of coercive rollback include any attacks made to compel a state to halt its proliferation program. Strategic bombing can be directed to any portion of a state's infrastructure, and the focus of attack can be changed as time passes. Such attacks were applied to Serbia in 1999 in order to force that government to make changes in its relationship with the province of Kosovo. This type of attack could also be used for nonproliferation purposes.

Indirect methods are not limited to bombing. A general invasion of a proliferating state can certainly put an end to its proliferation program, provided that the invasion is complete enough. Driving the national authorities out of the capital alone is not sufficient: occupation must extend to the proliferation facilities. A general invasion could follow a period of strategic bombing and attacks on military defenses. The attack may be directed at finding and destroying the nuclear weapon facilities or at destroying the economic potential of the state to inhibit future redevelopment. A change of government, perhaps monitored by occupation forces, may be necessary.

The lower levels of forced rollback, up to bombardment of proliferation facilities, can be accomplished with little political effect or requirements in the state or states conducting the rollback. These are brief military actions and can be completed before any public information is provided, and there is no requirement to provide public justification before the fact. Because the results of such an attack are affected by the surprise with which it occurs, there is good justification for such actions to be undertaken with no public discussion whatsoever.

Strategic bombing and general invasion—in other words, war—require both military potential and, in democracies, government support. Some degree of popular support is necessary in order to secure government support, either because of democratic controls on government actions or because military actions taken without popular support can lead to unrest, as we saw in Vietnam and, more recently, in Chechnya.

Depending on the military power of the target country, the costs of such an action on the part of the invader can be significant. Hundreds, thousands, or tens of thousands of casualties might occur between invading and occupying forces. If the goal of the general invasion is to simply destroy proliferation facilities, such costs might be seen by many states as too high. Destroying proliferation facilities alone only sets a program back a few years. Recruitment of new personnel and reconstruction is likely to occur immediately. If the goal is to prevent nuclear proliferation for the long-term, occupation forces may be needed. Failure to occupy a defeated state permits the possibility that the government policy to proliferate will not change (e.g., Iraq). With an occupation, however, guerrilla actions can exact a significant toll. The losses that guerrilla forces can inflict, even in modern times, were clearly demonstrated in the 1994-1996 Chechnya conflict.[43]

Casualties among the attacking forces might be reduced, as they were in the Gulf War through the use of air power in destroying defense forces. The threat of further bombardment and invasion was employed to obtain a surrender settlement, in which Iraq agreed to allow U.N. inspectors to search for and destroy all components of its WMD and missile programs. In general, however, air power does not put military forces in control on the ground, and military actions to accomplish this objective are more vulnerable to counteraction.

Beyond the purpose of enforcing nonproliferation, general invasion or strategic bombing may require that the proliferating state deserve such actions for wider reasons. This is particularly true in the current political climate in those states with the military potential to conduct or lead

Table 1: Attributes of Coercive Rollback Options

Class	Action	Political concurrence	Cost of military action ($)	Potential risks	Nominal delay
Direct	Assassination of key individuals	Executive decision	Hundreds of thousands	Loss of operatives/ exposure/retaliation	Days to years
Direct	Bombing of individuals	Executive decision	Hundreds of thousands	Compromise of missile technology/ retaliation	Days to years
Direct	Sabotage of key equipment	Executive decision	Hundreds of thousands	Loss of operatives/ exposure/retaliation	Months to years
Direct	Bombing of key equipment	Executive decision	Millions	Compromise of missile technology/ retaliation	Months to years
Direct	Surgical invasion	Executive decision	Millions	Loss/capture of personnel/retaliation	Years
Direct	Bombing of facilities	Executive decision	Tens of millions	Compromise of missile technology/ retaliation	Years
Indirect	Bombing of infrastructure	Governmental decision	Hundreds of millions	Loss of aircraft/ aircrews/retaliation	Decades
Indirect	General invasion	Intergovern-mental decision	Billions	Loss/capture of personnel/retaliation	Decades

such military actions. Moreover, all countries of proliferation concern today, such as Iran, Iraq, and North Korea, have significant military resources, including, in some cases, chemical and/or biological weapons and missiles able to strike regional allies. Use of these in retaliation could raise the costs of invasion considerably.

Considering these factors, general invasions are likely to be useful for nonproliferation purposes solely against states that do not have significant military forces (such as Panama, Grenada, Haiti, and Somalia). However, states with this low level of military force are not likely to have the resources to even commence a WMD program.

DEFENSES AGAINST COERCIVE ROLLBACK

There are obvious defenses against coercive rollback that a middle-sized power might use upon engaging in a nuclear weapons development program. These defenses may be military, or they may take more subtle forms. Military defenses, including internal security, can play a significant role in defending national government figures and key technical personnel, and in defending against surgical or general invasion. However, traditional air defense capability is not effective in countering strategic missile bombardment. Furthermore, missile strikes may be used to eliminate air defense capability, so that aerial bombing (a much cheaper means of strategic bombing) can follow. Preliminary planning and location selection on the part of the proliferator have the potential to render forced rollback nearly impossible with non-military means. Effective defenses include deception, dispersal, and depth.

Deception plays many roles. National denial of a program that actually exists certainly constitutes deception, but deception can also occur with regard to the perceived size of the program, its character, and its location. Forced rollback, such as that initiated by Israel against Iraq in 1981, is dependent on good information about the program, specifically where and when targeting of the WMD facilities is feasible. By camouflaging such facilities, limiting the opportunities for espionage, and providing false or confusing indicators of proliferation activity, a proliferating state can reduce the possibility of missile or aerial bombing of its proliferation facilities. This deception accomplishes two things: (1) it renders the determination of accurate information about the program difficult, and (2) it undermines the ability of the state collecting the information to rally support from other states to increase the level of coercion. The cost of such deception is low compared to the cost of the program, and it does not require any special expertise.

Dispersal provides a second defense against outside intervention. By not concentrating nuclear facilities in one location, and by blending them with facilities that are not connected in any way with proliferation, no concentrated target is provided. For example, a good portion of the research preliminary to the production of nuclear materials can be done in a university setting, and destroying university facilities would be difficult, if not impossible, to justify. However, assassination is more difficult to defend against with dispersed facilities.

A third defense involves hiding the required facilities underground, where missiles cannot reach. This, as with the other two defenses, increases the costs of the programs; but it also increases the difficulty of attempted attack or sabotage. This is not a new idea, as there are examples of nuclear materials facilities already underground, such as Dimona in Israel and Krasnoyarsk-26 in Russia.[44]

Technology has also been progressing rapidly in excavation. Modern self-propelled tunneling machinery allows nuclear facilities to be built many times faster and cheaper than they were 20 years ago. Automated tunneling equipment has been available for decades and continues to become more efficient and less expensive. Self-propelled equipment, specifically tunnel boring machines (TBM), allow a tunnel two to 10 meters (m) in diameter to be bored at the rate of several m per day or more.[45] A recent record set by a TBM was 150m a day, with a diameter of 6.4m and a height of 4.3m, as part of a $20 million project.[46] Furthermore, the use of such TBM is no longer restricted to locations with hard rock.[47] Other types of automated equipment allow supports and linings to be put in place at the same rate as the boring proceeds. This equipment is available on the international marketplace and is used for mining and civilian construction of subways, watercourses, and other underground facilities.

The tunnel lengths needed to put a proliferation facility underground would be in the range of a few hundreds to a few thousands of meters. The costs involved in excavating an underground facility capable of housing a modern nuclear facility are a few tens of millions of dollars and would create delays of approximately a year or less. The size of an AVLIS plant capable of producing the same uranium separation as a gaseous diffusion plant, for example, was estimated at 5,000 square meters.[48] For the purpose of enriching uranium in sufficient quantities for a few weapons a year, only a fraction of this space would be required. TBMs have lowered the cost and delay barriers that might have formerly inhibited the placing of facilities underground, and the prevalence of it for legitimate mining applications in most of the larger countries means it is readily available to any potential proliferating state. Worldwide tunneling activity amounts to millions of meters bored per year, indicating that TBMs are widely available, manufacturing occurs in many countries, and the technology has been dispersed.[49] Indigenous tunneling expertise and support services may be somewhat less prevalent, but they do not represent a significant challenge.

Missiles are ineffective against underground facilities, and only invasion of the facilities can provide much hope of destruction. The alternative is the destruction of entrances to the facility by missile attack. This may result in a sealing of the facility until excavation can open it up again. However, multiple entrances can be created, with some of them hidden and unused except for emergency purposes. Thus, an attack on entrances could result in virtually no delay and only a small cost in rebuilding the entrances to the facility. Alternately, an underground area that was not designed for such attacks could be shut down for some days while the entrances are reconstructed. Only repeated attacks on entrances would result in a serious delay to the program.

Underground facilities also provide a means of denying information about the facilities to overhead observation and additionally produces a natural compartmentalization that inhibits espionage. Facilities that cannot be dispersed—such as reactors, reprocessing or enrichment plants, and weapons production facilities—are likely to be developed underground by any proliferator concerned about the possibility of coercive rollback. Reactors require a means of dispersing the heat generated, and so the locations for wholly underground reactors are limited to those similar to Krasnoyarsk-26, where river water could be diverted to cool the reactors. This necessarily produces a heat signature, which would be an indicator of some heat-producing activity. Whether or not a state using a reactor to proliferate could arrange for sufficient heat dispersal to lower the heat signature is an open question. Other facilities have the same problem. AVLIS uses lasers that are not efficient and thereby generates much heat as a by-product. More efficient lasers would both reduce the heat signature and make the siting of proliferation activities underground less demanding.

CHANGES IN THE ROUTE TO NUCLEAR PROLIFERATION

In the coming decades, the economic and technical factors described above are likely to change the path to nuclear proliferation for newly proliferating states. The examples of India and Pakistan, countries that have proliferated without major economic reprisal, have shown how to limit non-coercive counterproliferation measures. The consensus seems to be that economic sanctions, at least limited ones, are ineffectual in pressuring a country to abandon a well-established nuclear weapons program. Popular support in both countries provides foundations for the programs, and political decisions to eliminate them are not likely.

International trade also inhibits the effect of sanctions. When economic sanctions affect trade in such a way that they hurt major trading states as well as the proliferating state, there is less international consensus on applying them effectively and rigidly.

To forestall forced rollback or other coercive counterproliferation measures, states might choose to keep their programs covert until a set of effective weapons can be built. This is more likely than the state withdrawing publicly from the NPT—unless of course, political events create a situation for a mass withdrawal. A proliferating state should avoid attracting international response as a result of belligerent actions (i.e., invasion of a neighboring state or blatant mistreatment of minorities) until its nuclear arsenal is available.

Finally, deception, including the dispersal of facilities and the creation of underground, “invisible” facilities, might be used to prevent counterproliferation of any variety short of invasion and war.

IMPLICATIONS FOR NONPROLIFERATION ACTIVITY

With this path to proliferation possible, what changes could be made in national and international nonproliferation activity in order to continue its record of success? There are, of course, preventive measures that can be enhanced, including the amelioration of security problems that might spur nuclear proliferation. The continued encouragement of international nonproliferation norms, along with strengthening the nonproliferation regime through the various relevant treaties, is also important. If these are not enough, there are three stages to further activity: (1) the detection of states attempting to covertly proliferate;

(2) the development of knowledge about the details of the proliferation program; and (3) taking steps to end it.

For the first stage, there must be a recognition that existing signatures of nuclear proliferation, such as characteristic facilities being built in visible locations, may not be available. More effort will be needed in determining if a state is proliferating and in obtaining credible evidence to back up accusations. One indicator, export control violations, may become unavailable as technological advances remove the need for states to import sensitive equipment, materials, or technology. Instead, high technology devices might be needed to detect the existence of such programs. These devices involve sampling and forensics.

For example, AVLIS does not use uranium hexafluoride, and therefore no telltale equipment able to resist corrosion from this chemical, a hallmark for export control, need be acquired. The technologies of laser enrichment are also easier to research unobtrusively than those of earlier enrichment processes. The technology base necessary for a country to develop a laser enrichment facility is more widespread than that of earlier technology, as high-power and tunable laser research is being carried out in many locations for purposes entirely unrelated to enrichment of nuclear materials. However, the installation of production-size laser isotope separation systems is more complex, and other signatures might be generated by this activity. Since plutonium from spent fuel can be enriched using the same technology, the attractiveness of this material will increase. Instead of downplaying the importance of this material, means of detecting its diversion should be enhanced.

The second stage, classification, requires both remote and in-site sampling. Facilities requiring isolation may be put underground, and hence much less information on them would be available from satellite photography. Even more deceptive would be the placing of these underground facilities inside a military base. This would provide cover for the facilities, as many military storerooms and command posts are routinely built underground. Excavation alone would not be a determinant of proliferation. Neither would signatures of generic laser research, as laser technology has many military applications as well. More precise understanding of the various types of laser isotope enrichment is required in order to aid in such discrimination.

The third step is destruction of the program. Once it is classified and proven, diplomatic means and international pressure can be used to promote its termination. However, these techniques may not work if the determination is made too late in the program's existence. Forcible means may be considered. To achieve a significant effect, either surgical destruction of key facilities or general invasion might be required.

Whether surgical invasion and destruction of nuclear proliferation facilities can succeed depends a great deal on the type of facility and the capability of the forces guarding it, as well as the military forces of the state in general. These missions are very complex actions subject to much uncertainty and requiring specially trained and equipped forces. When one considers, for example, the difficulty the United States faced when attempting to rescue hostages from Iran in 1980, one can imagine the level of difficulty that might be faced when trying to sabotage or destroy a state's nuclear facility.[50]

If the proliferating state has made a serious attempt to maximize its defenses against counterproliferation measures of this type, underground facilities could be built on a military facility with only a few, well-guarded entrances, making access difficult. By delaying entrance into the facility, defensive forces provide time for larger response forces to arrive and engage the attacking team. Military planners contemplating forced rollback via surgical invasion would be faced with a difficult task. Capture of the raiding force would be a major political embarrassment. Avoiding any possibility of capture of the rescue force was a dominant factor in the planning for the Iran hostage rescue. Only a specialized military force, capable of military operations as well as the ability to understand, recognize, and eliminate such facilities on sight, would have the potential to achieve success. Planning and training on simulated underground facilities would be necessary. For such a worst-case defense scenario, it is likely that the forces involved would be significantly larger than the forces used in the Iran rescue attempt. Thus, if such operations are to be a part of the option palette for counterproliferation, planning for them and the devotion of adequate resources must be accomplished.

General invasion is the last, and most extreme, option for rolling back a state's WMD program. The goal of the invasion is to occupy the state and forcibly change the government. If done properly, this could eliminate a proliferation program and prevent its reemergence.

Attacks aimed at achieving limited goals have only been performed against states with very small military potential, however. Grenada and Haiti possessed only police forces with small arms capability; Panama's military was also ineffective. Furthermore, there was abundant intelligence on Panama's military due to the collocation of U.S. forces at the Panama Canal. The military problems the U.S. forces faced in Somalia, where forces were also poorly organized and armed, gives an indication that an occupation (as opposed to a war of destruction) is very difficult to do successfully.[51] Invasion for the purpose of occupation might turn into a prolonged war in countries with significantly larger military power than Panama. Furthermore, without popular support in the target country for the invasion, there would likely be guerrilla-type response actions, even if the occupation forces were able to quickly disable and disarm the military. This would imply that large-scale military invasions for the purpose of counterproliferation must be short and eliminate nuclear facilities rapidly, with quick retreat from the country. Military and political planning for such a possibility would provide a better understanding of this option. Then, the value of causing a delay in proliferation could be better compared with the potential costs.

SUMMARY

The motivations driving proliferation may change from prestige and mutual deterrence to the assurance of latitude to accomplish internal and regional security tasks. The route that a mid-sized state might choose for nuclear proliferation for maximum success and minimal risk of serious adverse consequences may be changing. The changes are driven by the same two factors that have driven proliferation issues in the past: economics and technology. Technology changes in at least four areas are relevant: laser isotope separation, automated tunneling, cruise missiles, and AIP submarines. These reduce the cost, delay, and risk in developing a minimum nuclear weapons capability. The counterproliferation tools developed over the last decades to promote nuclear nonproliferation—including export controls, sanctions, and the threat of coercive rollback—as they are now considered, may not be effective tools for the next decades. Emphasis must be given to both seeking better ways to detect and assess nuclear proliferation and to reversing it. Otherwise, there may be significant proliferation in the next few decades. These improvements should be undertaken as soon as feasible, as should contingencies for dealing with the failure to halt proliferation. Since the preparation of defensive capability against emerging nuclear threats may require more time than the proliferation timetable of a newly proliferating state, immediate steps should be taken to address this.

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