Introduction and Summary

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This background paper explores the technical pathways by which states might acquire nuclear, chemical, and biological weapons and the systems to deliver them. It also assesses the level of effort, commitment, and resources required to mount such developments. The paper is a companion to the OTA report *Proliferation of Weapons of Mass Destruction: Assessing the Risks,* which describes what nuclear, chemical, and biological weapons can do and how they might be used.[1] That report also analyzes the consequences of the spread of such weapons for the United States and the world, surveys the array of policy tools that can be used to combat proliferation, and identifies tradeoffs and choices that confront policymakers. A forthcoming report will analyze specific sets of nonproliferation policy options in detail.

The technical hurdles that must be surmounted to develop nuclear, chemical, and biological weapons are summarized in table 1-1, which also appeared in OTA's earlier report.[2] Those steps that are particularly time-consuming or difficult for proliferants to master without outside assistance can be exploited to control proliferation. Conversely, steps that are relatively easy, or that make use of widely available know-how and equipment, make poor candidates for control efforts. Understanding the extent to which ''dual-use' technologies or products—those also having legitimate applications-are involved in the development of weapons of mass destruction is important, since both the feasibility of controlling dual-use items and the implications of doing so depend on the extent of their other applications.

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[1] U.S. Congress, Office of Technology Assessment, *Proliferation of Weapons of Mass Destruction: Assessing the Risks,* OTA-ISC-559 *(Washington* DC: U.S. Government Printing Office, August 1993).

[2] Ibid., pp. 1011.

Table l-l—Technical Hurdles for Nuclear, Biological, and **Chemical Weapon Programs**

	Nuclear	Biological	Chemical
Nuclear materials or lethal agents production			
Feed materials	Uranium ore, oxide widely available; plutonium and partly enriched uranium dispersed through nuclear power programs, mostly under international safeguards.	Potential biological warfare agents are readily available locally or internationally from natural sources or commercial suppliers.	Many basic chemicals available for commercial purposes; only some nerve gas precursors available for purchase, but ability to manufacture them is spreading.
Scientific and technical personnel	Requires wide variety of expertise and skillful systems integration.	sophisticated research and development unnecessary to produce commonly known agents. industrial microbiological personnel widely available.	Organic chemists and chemical engineers widely available.
Design and engineering knowledge	Varies with process, but specific designs for producing either of the two bomb-grade nuclear materials can be difficult to develop: ■ Separation of uranium isotopes to produce highly enriched uranium; . Reactor production and chemical processing to produce plutonium,	Widely published; basic techniques to produce known agents not difficult.	Widely published. Some processes tricky (Iraq had difficulty with tabun cyanation, succeeded at sarin alkylation; however, sarin quality was poor).
Equipment	Varies with different processes but difficulties can include fabrication, power consumption, large size, and operational complexity: ■ Electromagnetic separation equipment can be constructed from available, multiple-use parts; ■ Equipment for other processes is more specialized and difficult to buy or build.	Widely available for commercial uses. Special containment and waste-treatment equipment may be more difficult to assemble, but are not essential to production.	Most has legitimate industrial applications. Alkylation process is somewhat difficult and is unusual in civilian applications. Special containment and waste treatment equipment may be more difficult to assemble, but are not essential to production.

Monitoring the proliferation of weapons of mass destruction, or conversely monitoring compliance with nonproliferation agreements, depends on detecting and identifying various indicators or *signatures* associated with the development, production, deployment, or use of such weapons. This paper also identifies signatures that, if detected, might reveal the existence of or progress in programs to develop weapons of mass destruction and their delivery systems.

OTA's earlier report summarized the material included in chapters 2 through 5 of this report.[3]

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[3] *Ibid.,* pp. 33-43.

Table 1-1-(Continued)

	Nuclear	Biological	Chemical
Plant construction and operation	Costly and challenging. Research reactors or electric power reactors might be converted to plutonium production.	With advent of biotechnology, small-scale faclities now capable of large-scale production.	Dedicated plant not difficult. Conversion of existing commercial chemical plants feasible but not trivial.
Overall cost	Cheapest overt production route for one bomb per year, with no international controls, is about $200 million; larger scale clandestine program could cost 10 to 50 times more, and even then not be assured of success or of remaining hidden. Black-market purchase of ready-to-use fissile materials or of complete weapons could be many times cheaper.	Enough for large arsenal may cost less than $10 million.	Arsenal for substantial military capability (hundreds of tons of agent) likely to cost tens of millions of dollars.
Weaponization			
Design and engineering	Heavier, less efficient, lower yield designs easier, but all pose significant technical challenges.	Principal challenge is maintaining the agent's potency through weapon storage, delivery, and dissemination. Broad-area dissemination not difficult; design of weapons that effectively aerosolize agents for precision delivery challenging (but developed by U.S. by'60s).	Advanced weapons somewhat difficult, but workable munition designs (e.g., bursting smoke device) widely published.
Production equipment	Much (e.g., machine tools) dual-use and widely available, Some overlap with conventional munitions production equipment.	Must be tightly contained to prevent spread of infection, but the necessary equipment i snot hard to build.	Relatively simple, closely related to standard munitions production equipment.

SOURCE: Office of Technology Assessment, 1993.

For those readers who do not have a copy of that publication, the summary is repeated below.

NUCLEAR WEAPONS

Material Production

In terms of costs, resources required, and possibility of discovery, the difficulty of obtaining nuclear weapon materials—plutonium or highly enriched uranium—today remains the greatest single obstacle most countries would face in pursuing nuclear weapons. Even straightforward methods of producing such material indigenously (such as building a small reactor and a primitive reprocessing facility to produce plutonium and recover it from irradiated reactor fuel) would require at least a modest technological infrastructure and hundreds of millions of dollars to carry out. Moreover, once such a facility became known, it could generate considerable pressure from regional rivals or the international community. The costs of a full-scale indigenous nuclear weapon program-especially if clandestine-can be substantially higher than for a program largely aimed at producing just one or two bombs and carried out in the open. Iraq spent 10 to 20 times the cost of such a minimal program-many billions of dollars-to pursue multiple uranium enrichment technologies, to build complex and sometimes redundant facilities, to keep its efforts secret, and to seek a fairly substantial nuclear capability. Few countries of proliferation concern can match the resources that Iraq devoted to its nuclear weapon program. (Iran, however, probably could.)

Since production of nuclear materials is generally the most difficult and expensive part of producing a nuclear weapon, the leakage of significant amounts of weapon-grade material from the former Soviet Union would provide a great advantage to potential proliferants. Indeed, the possibility of black-market sales of weapon-usable materials may represent one of the greatest proliferation dangers now being faced. Even the covert acquisition of low-enriched uranium, which can fuel nuclear reactors but is not directly usable for nuclear weapons, could be advantageous to a proliferant by enhancing the capacity of its isotope separation plants.

This ominous prospect notwithstanding, nuclear materials suitable for weapon purposes have to date been extremely difficult to obtain from countries that already possess them. There is no reliable evidence that any militarily significant quantities of nuclear weapon material have been smuggled out of the former Soviet Union. The vast majority of nuclear material in nonnuclear weapon states is safeguarded by a comprehensive system of material accountancy and control administered by the International Atomic Energy Agency (IAEA). These safeguards are not perfect, but they provide high levels of confidence that significant quantities of nuclear material have not been diverted from safeguarded nuclear reactors. Diversion would be more difficult to detect from facilities such as fuel fabrication plants, uranium enrichment plants, and plutonium reprocessing facilities that process large quantities of nuclear material in bulk form, as opposed to handling it only in discrete units such as fuel rods or reactor cores. At present, however, there are no large facilities of this type under comprehensive IAEA safeguards in countries of particular proliferation concern.[4] At least in the short run, the diversion of safeguarded materials poses less of a threat to the nonproliferation regime than the black-market purchase or covert indigenous production of nuclear materials.

Under current European and Japanese plans for reprocessing and limited reuse of plutonium from commercial reactor fuel, the current worldwide surplus of some 70 tonnes of safeguarded, separated reactor-grade plutonium-the type produced by commercial nuclear reactors in normal operation-will likely continue to grow through the 1990s by more than 10 tonnes per year. Reactor-grade plutonium is more radioactive and more difficult to handle than *weapon-grade* plutonium, which is produced specifically for use in nuclear weapons, but it can still be used to make a crude nuclear weapon of significant (though probably less predictable) yield. Nevertheless, the states that have sought nuclear weapons have gone to great lengths to produce weapon-grade materials-either highly enriched uranium or weapon-grade plutonium-rather than reactor-grade plutonium. (Note that some types of nuclear power reactors, including ones in India, South Korea, and North Korea, can produce either reactor-grade or weapon-grade plutonium, depending on how they are operated.)

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[4] Brazil has a medium-sized fuel fabrication facility under IAEA safeguards, and South African enrichment facilities are coming under safeguards with South Africa's announced destruction of its nuclear weapons and its accession to the NPT. Neither state is considered an active proliferation threat at present.

Other Technical Barriers

Unlike chemical and biological weapons, whose lethality is roughly proportional to the amount of agent dispersed, nuclear weapons will not produce any yield at all unless certain conditions are met: a minimum "critical mass" of nuclear materials must be present, and that material must be brought together with sufficient speed and precision for a nuclear chain reaction to take place. A proliferant must master a series of technical hurdles in order to produce even a single working weapon.

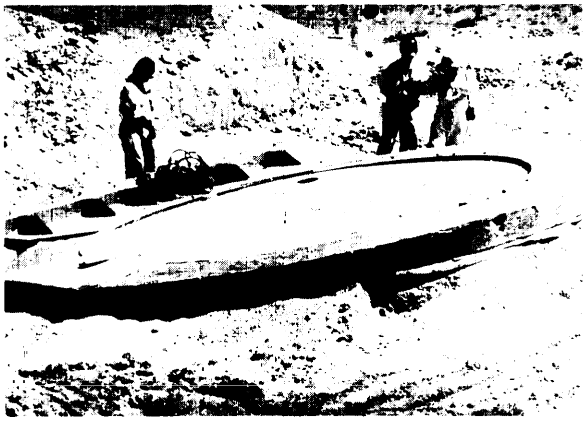
Nuclear weapons are so destructive that they place few requirements on the accuracy of delivery systems for any but the most protected targets. Most proliferants would likely be able to design frost-generation nuclear weapons that were small and light enough to be carried by Scud-class missiles or small aircraft. Given additional technical refinement, they might be able to reduce warhead weights to the point where the 500 kg (1,100 pound) delivery threshold originally established by the Missile Technology Control Regime no longer provides a reliable barrier to nuclear-capable ballistic or cruise missiles.[5]

Although nuclear weapons were first developed 50 years ago and the basic mechanisms are widely known, much of the detailed design information, and particularly the knowledge gleaned by the nuclear weapons states from decades of design and testing, remains classified. Much of this information can be reconstructed by a dedicated proliferant, but it will take time and money. Moreover, ‘‘weaponizing” a nuclear warhead for reliable missile delivery or long shelf-life creates additional hurdles that could significantly increase the required development effort. Therefore, having access to key individuals-such as those from the former Soviet nuclear weapon program---could significantly accelerate a nuclear program, primarily by steering it away from unworkable designs. Specific individuals could fill critical gaps in a given country's knowledge or experience, adding greatly to the likelihood that a program would succeed.

High-performance computers (so-called "supercomputers" in the 1980s) are *not required* to design first-generation fission weapons. Thus, placing strict Limits on their exports would be of minimal importance compared with limiting technologies for nuclear materials production.

Monitoring Nuclear Proliferation

Production of nuclear materials provides many signatures and the greatest opportunity for detecting a clandestine nuclear weapon program. Even so, a large part of the Iraqi program was missed. Since members of the Nuclear Non-Proliferation Treaty (other than the acknowledged nuclear weapon states) are not permitted to operate unsafeguarded facilities handling nuclear materi-


LOS ALAMOS NATIONAL LABORATORY

Iraqi electromagnetic isotope separation (EMS) equipment, uncovered after having been buried in the desert to hide it from United Nations inspectors. Iraq's EMIS program to enrich uranium for nuclear weapons had not been detected by Western intelligence agencies prior to the GuJf War.

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[5] Broadening its focus, the Missile Technology Control Regime now covers missiles capable of delivering chemical and biological weapons as well as those that could be used to deliver nuclear weapons. Consequently, missiles with payloads below 500 kg are included as well.

als, the existence of any such facilities would probably indicate an illegal weapon program.[6]

Nuclear tests at kiloton yields or above would probably be detectable by various means, especially if multiple tests were conducted. However, such tests are not necessary to field a workable weapon with reasonably assured yield. Similarly, the deployment of a very small number of nuclear weapons might not be easily detected.

Implications of Old and New Technologies

Low- and medium-level gas *centrifuge technology* for enriching uranium may become increasingly attractive to potential proliferants for a variety of reasons, including availability of information about early designs, difficulty of detection, ease of producing highly enriched uranium, and potential availability of equipment from the former Soviet Union. Modern, state-of-the-art centrifuges could lead to even smaller, more efficient, and relatively inexpensive facilities that would be diffificult to detect remotely.

In the longer run, *laser isotope separation* techniques and *aerodynamic separation* may have serious proliferation potential as means of producing highly enriched uranium for nuclear weapons. Openly pursued by more than a dozen non-nuclear-weapon states, *laser* enrichment technologies use precisely tuned laser beams to selectively energize the uranium-235 isotope most useful for nuclear weapons and separate it from the more common uranium-238 isotope. Laser facilities would be small in size and could enrich uranium to high levels in only a few stages. They could therefore prove to be difficult to detect and control if successfully developed as part of a clandestine program. Nevertheless, considerable development work remains to be done before this method can be made viable or can compete with existing enrichment technologies. Even for the advanced industrialized countries, constructing operational facilities will remain very difficult Some *aerodynamic techniques*—which use carefully designed gas flows to separate the lighter uranium-235 from the heavier uranium-238-require fairly sophisticated technology to manufacture large numbers of precision small-scale components, but they do not otherwise pose technical challenges beyond those of other enrichment approaches.

CHEMICAL WEAPONS

The technology used to produce chemical weapons is much harder to identify unambiguously as weapons-related than is that for nuclear materials production technology, and relevant know-how is much more widely available. Although production techniques for major chemical weapon agents involve some specialized process steps, detailed examples can be found in the open literature and follow from standard chemical engineering principles. Unlike nuclear proliferation, where the mere existence of an unsafeguarded nuclear facility in an NPT member state could be sufficient evidence of intent to produce weapons, many legitimate chemical facilities could have the ability to produce chemical agent. Intent cannot be inferred directly from capability.

Agent and Weapon Production

Certain chemical agents such as mustard gas are very simple to produce. Synthesis of nerve agents, however, includes some difficult process steps involving highly corrosive or reactive materials. A sophisticated production facility to make militarily significant quantities of one class of nerve agents might cost between $30 and $50

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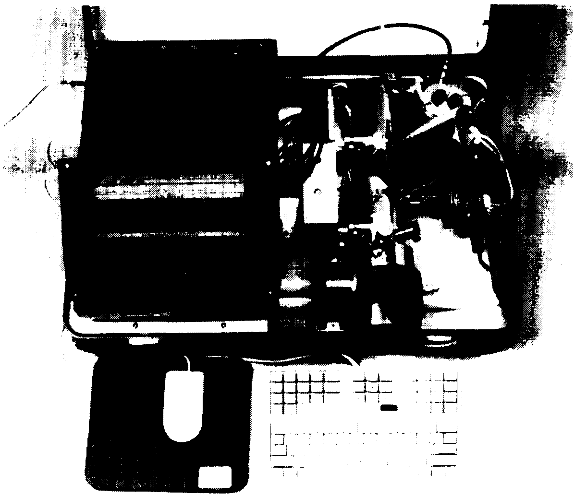
[6] The exception to this statement would be unsafeguarded facilities dedicated to military purposes unrelated to nuclear weapons, such as naval nuclear propulsion. Such uses are not prohibited by the Nuclear Non-proliferation Treaty. They fall outside IAEA jurisdiction however, since IAEA safeguards pertain only to peaceful-e. g., nonmilitary-applications of nuclear power, See Ben Sanders and John Simpson, *Nuclear Submarines and Non-Proliferation: Cause for Concern,* PPNN Occasional Paper Two (Southampton, England: Centre for International Policy Studies, University of Southampton, for the Programme for Promoting Nuclear Non-Proliferation 1988).

million, although dispensing with modem waste-handling facilities might cut the cost in half. Some of the equipment needed may have distinctive features, such as corrosion-resistant reactors and pipes and special ventilation and waste-handling equipment, but these can be dispensed with by relaxing worker safety and environmental standards and by replacing hardware as it corrodes. Moreover, production is easier if a proliferant country is willing to cut corners on shelf-life, seeking only to produce low-quality agent for immediate use.

Chemical-warfare agents can be produced through a wide variety of alternative routes, but relatively few routes are well-suited for large-scale production. Just because the United States used a particular production pathway in the past, however, does not mean that proliferant countries would necessarily choose the same process.

In general, commercial pesticide plants lack the precursor chemicals (materials from which chemical agents are synthesized), equipment, facilities, and safety procedures required for nerve-agent production. Nevertheless, multipurpose chemical plants capable of manufacturing organo-phosphorus pesticides or flame retardants could be converted in a matter of weeks or months to the production of nerve agents. The choice between converting a commercial plant in this manner and building a clandestine production facility would depend on the urgency of a country's military requirement for a chemical weapon stockpile, its desire to keep the program secret, its level of concern over worker safety and environmental protection, and the existence of embargoes on precursor materials and production equipment.

Agent production, however, is several steps removed from an operational chemical weapon capability. The latter requires design and development of effective munitions, filling the munitions before use, and mating them with a suitable delivery system.



LAWRENCE LIVERMORE NATIONAL LABORATORY

Portable gas chromatograph/mass spectrometer (GCl MS) developed to support onsite analysis for the Chemical Weapons Convention. This equipment can detect and identify minute quantities of organic chemicals controlled by the CWC.

I Monitoring Chemical Weapon Proliferation

Direct detection of chemical warfare agents in samples taken from a production facility would be a clear indicator of weapon activity, since these agents have almost no civil applications.[7] However, considerable access to production facilities is required to ensure that appropriate samples have been collected. Moreover, some of the substances produced when chemical agents break down in the environment are also produced when legitimate commercial chemicals break down, so detection of final degradation products does not necessarily indicate agent production. Nevertheless, the suite of degradation products associated with a given chemical agent production process would provide a clear signature.

Other than the agent itself, or an ensemble of degradation products, chemical agent production has few unequivocal signatures. Moreover, highly reliable technologies to detect chemical agent production from *outside the* site are not currently

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[7] Nitrogen mustards have some use in cancer chemotherapy, and phosgene and hydrogen cyanide have industrial applications.

available. Unlike nuclear weapon facilities, which generally exhibit fairly clear signatures, civilian chemical plants have multiple uses, are hundreds of times more numerous than nuclear facilities, and are configured in different ways depending on the process involved. Moreover, many of the same chemicals used to make chemical agents are also used to make pharmaceuticals, pesticides, and other commercial products. Since many different types of equipment are suitable for chemical agent production, plant equipment per se does not provide a reliable means of distinguishing between legitimate and illicit activities. Nevertheless, some potential signatures of chemical weapon development and production exist, and a set of multiple indicators taken from many sources may be highly suggestive of a production capability.

Indicators at suspect locations that may contribute to such an overall assessment include: visual signatures such as testing munitions and delivery systems; distinctive aspects of plant design and layout, including the use of corrosion-resistant materials and air-purification systems; presence of chemical agents, precursors, or degradation products in the facility's production line or waste stream; and biochemical evidence of chemical agent exposure (including that due to accidental leaks) in plant workers or in plants and animals living in the vicinity of a suspect facility. Nevertheless, the utility of specific signatures depends on how a given weapon program operates, including the choice of production process and the extent of investment in emission-control technologies. Detection capabilities that are decisive under laboratory conditions may be rather inconclusive in the field—particularly if the proliferant has been producing related legitimate chemicals (e.g., organophosphorus pesticides) in the same facility and is willing to expend time, effort, and resources to mask, obscure, or otherwise explain away chemical agent production activities. Testing of chemical agents and training troops in their use might be masked by experiments with or training for the use of smoke screens. A robust inspection regime must therefore comprise an interlocking web of inspections, declarations, notifications, and data fusion and analysis, all of which a cheater must defeat in order to conceal his violations. Focusing monitoring efforts at a single point-even one thought to be a crucial chokepoint-would allow the cheater to focus his efforts on defeating them.

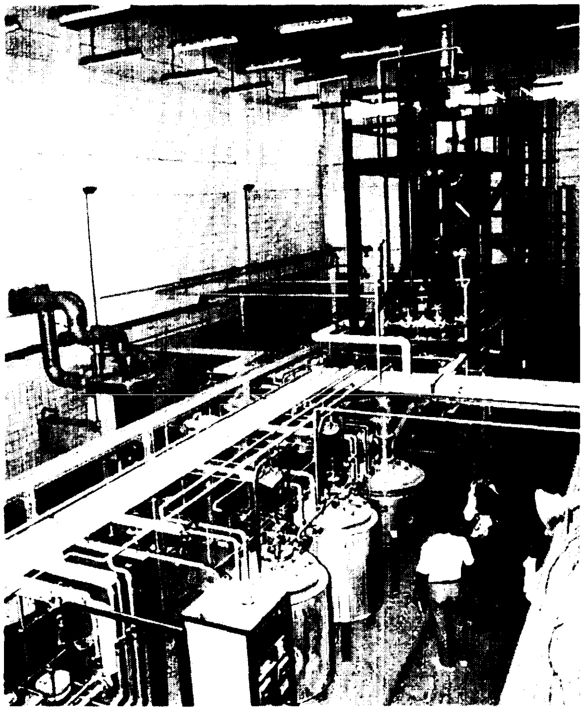
Keeping a production program covert forces other tradeoffs. Some of the simplest production pathways might have to be avoided since they use known precursors or involve known production processes. Purchasing equipment from multiple suppliers to avoid detection, or jury-rigging facilities from used equipment, might increase hazards to the workforce and nearby populations.

BIOLOGICAL WEAPONS

Biological-warfare agents are easier to produce than either nuclear materials or chemical-warfare agents because they require a much smaller and cheaper industrial infrastructure and because the necessary technology and know-how is widely available. Moreover, it would not be difficult to spread biological agents indiscriminately to produce large numbers of casualties, although it is much more difficult to develop munitions that have a predictable or controllable military effect.

Agent and Weapon Production

The global biotechnology industry is information-intensive rather than capital-intensive. Much of the data relevant to producing biological agents is widely available in the published literature and virtually impossible for industrialized states to withhold from potential proliferants. A widespread support infrastructure of equipment manufacturers has also arisen to serve the industry. Therefore, producing biological agents would be relatively easy and inexpensive for any nation that has a modestly sophisticated pharmaceutical industry. Moreover, nearly all the equipment needed for large-scale production of



UN PHOTO, H. ARVIDSSON

United Nations inspectors assessing the biological weapon potential of Iraqi fermenters and other bioprocess equipment.

pathogens and toxins is dual-use and widely available on the international market.

One technical hurdle to the production of biological weapons is ensuring adequate containment and worker safety during agent production and weapons handling, although the difficulty of doing so depends on the level of safety and environmental standards. A government that placed little value on the safety of plant workers or the civilian population might well take minimal precautions, so that a biological-weapons production facility would not necessarily be equipped with sophisticated high-containment measures, Another challenge is ‘‘weaponizing’ the agents for successful delivery. Since microbial pathogens and toxins are susceptible to environmental stresses such as heat, oxidation, and dessication, to be effective they must maintain their potency during weapon storage, delivery, and dissemination.

A supply of standard biological agents for covert sabotage or attacks against broad-area targets would be relatively easy to produce and disseminate using commercially available equipment, such as agricultural sprayers. In contrast, the integration of biological agents into precise, reliable, and effective delivery systems such as missile warheads and cluster bombs poses complex engineering problems. Nevertheless, the United States had overcome these problems by the 1960s and had stockpiled biological warfare agents.

Monitoring Biological Weapon Production

Detection and monitoring of biological and toxin agent production is a particularly challenging task. Even use of biological weapons could in some cases be difficult to verify unambiguously, since outbreaks of disease also take place naturally. Thanks to advances in biotechnology, including improved fermentation equipment as well as genetic engineering techniques, biological and toxin agents could be made in facilities that are much smaller and less conspicuous than in the past. Moreover, the extreme potency of such agents means that as little as a few kilograms can be militarily significant. Since large amounts of agent can be grown from a freeze-dried seed culture in a period of days to weeks, large stockpiles of agent are not required, although some stocks of the munitions to be filled with these agents would be.

There are no signatures that distinguish clearly between the development of offensive biological agents and work on defensive vaccines, since both activities require the same basic know-how and laboratory techniques at the R&D stage. Moreover, almost all the equipment involved in biological and toxin weapon development and production is dual-use and hence will not typically indicate weapons activity. Indeed, the capacity to engage in illegal military activities is inherent in certain nominally civilian facilities. Some legitimate biological facilities can also convert rapidly to the production of biological warfare agents, depending on the degree of sophistication of the plant and on the required scale of production, level of worker safety, and environmental containment. At the same time, however, legitimate applications of biological or toxin agents (e.g., vaccine production and the clinical use of toxins) are relatively few at present. With the exception of a few vaccine production plants, such activities are largely confined to sophisticated biomedical facilities not normally found in developing countries, and these facilities generally do not engage in production except on a small scale. Moreover, given that the global biotechnology industry is still in its infancy, the number of" legitimate activities-from which the illegitimate ones would have to be distinguished-is still relatively small.

Sensitive analytical techniques such as polymerase chain reaction {PCR) analysis or use of monoclinal antibodies can identify trace quantities of biological agents and might be able to do so even after the termination of illicit activities. However, the existence of such sensitive laboratory techniques does not necessarily translate into a negotiated verification regime that might be instituted to monitor compliance with the Biological Weapons Convention, the international treaty that bans biological weapons. Other factors that must be assessed in establishing such a regime include the likelihood of detecting clandestine production sites, the ability to distinguish prohibited offensive activities from permitted defensive efforts, and the risk of divulging sensitive national security or proprietary information during inspections of U.S. facilities.[8]

Because of the difficulty of detecting clandestine biological and toxin weapon development and production, effective tracking of such programs will require integrating data from many sources, with a particular emphasis on human intelligence (agents, defectors, and whistleblowers). Some weaponization signatures (storage of bulk agents, preparation of aerosol dispensers, field testing, etc.) would probably be easier to detect than production signatures, but many such signatures could be concealed or masked by legitimate activities such as biopesticide R&D or use. Production and storage of components for BW munitions might also be masked by activities associated with conventional weapons, such as production of high explosives, bomb casings, or artillery shells. Since excessive secrecy might itself be indicative of offensive intent, greater transparency would tend to build confidence in a country's lack of offensive intentions.

Implications of New Technology

Genetic engineering is unlikely to result in ‘‘ supergerms’ significantly more lethal than the wide variety of potentially effective biological agents that already exist, nor is it likely to eliminate the fundamental uncertainties associated with the use of microbial pathogens in warfare. However, gene-splicing techniques might facilitate weaponization by rendering microorganisms more stable during dissemination (e.g., resistant to high temperatures and ultraviolet radiation). Biological agents might also be genetically modified to make them more difficult to detect by immunological means and insusceptible to standard vaccines or antibiotics. At the same time, genetic engineering techniques could be used to develop and produce protective vaccines more safely and rapidly.

Cloning toxin genes in bacteria makes it possible to produce formerly rare toxins in kilogram quantities. Moreover, molecular engineering techniques could lead to the development of more stable toxins. Even so, for the foreseeable

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[8] The United States has already determined that inspection procedures under the Chemical Weapons Convention, which allow the inspected party to negotiate the level of access to be provided to international inspectors, are sufficient to protect national security information and trade secrets, However, it is not necessary the case that the same inspection procedures would be suitable for the Biological Weapons Convention should a formal verification regime be instituted.

future, toxin-warfare agents are unlikely to provide dramatic military advantages over existing chemical weapons. It is possible that bioregulators and other natural body chemicals (or synthetic analogues thereof) might be developed into powerful incapacitants, but means of delivering such agents in a militarily effective manner would first have to be devised. Moreover, if warning of their use were provided, chemical weapon protective gear would blunt their impact.

DELIVERY SYSTEMS

Although military delivery systems such as ballistic missiles, cruise missiles, and combat aircraft are not essential to deliver weapons of mass destruction, they can do so more rapidly, more controllably, and more reliably than rudimentary means such as suitcases, car bombs, or civilian ships or planes. Controlling the spread of advanced delivery systems by no means would eliminate the dangers posed by weapons of mass destruction, particularly in terrorist applications. However, limiting the availability of these delivery systems would make it harder for states to use weapons of mass destruction for military purposes, particularly against well-defended, forewarned adversaries.

UN PHOTO, H. ARVIDSSON

United Nations inspector measuring an Iraqi Al-Husayn (modified Scud) missile in Baghdad.

Unlike nuclear, chemical, or biological weapons themselves, which are not traded openly due to treaty constraints or international norms, delivery systems such as aircraft and short-range antiship cruise missiles are widely available on international arms markets. Since the late 1980s, the United States and other Western industrialized countries have had some success at delegitimizing the sale of longer range ballistic and cruise missiles by creating the Missile Technology Control Regime (MTCR), the participants in which refrain from selling ballistic or cruise missiles with ranges over 300 kilometers, or with any range if the seller has reason to believe that they may be used to carry weapons of mass destruction. However, missiles with ranges up to 300 km-and to a lesser extent, up to 600-1,000 km-are already deployed in many Third-World countries. Combat aircraft are possessed by almost all countries of proliferation concern. Cruise missiles or other unmanned aerial vehicles with ranges much over 100 km are not yet widespread outside the acknowledged nuclear weapon states, but large numbers of cruise missiles, including antiship missiles, are available at lesser ranges.

In terms of payloads that can be carried to specfied ranges, the combat aircraft of virtually all countries of proliferation concern far surpass their missile capabilities. However, aircraft and missiles have different relative strengths—particularly in their ability to penetrate defenses—and the two systems are not fully interchangeable. Piloted aircraft have significant advantages over other delivery systems in terms of range, payload, accuracy, damage-assessment capability, and dispersal of chemical or biological agents. They can be used many times, usually even in the presence of significant air defenses. Missiles, however, are harder to defend against, and they offer distinct advantages for a country wishing to deliver a single nuclear weapon to a heavily defended area. Since missiles are not restricted to operating from airfields, they are also easier to hide from opposing forces. The wide range of motivations for acquiring ballistic missiles-prestige, diversifying one's forces, their psychological value as terror weapons, lack of trained pilots, and technology transfer and export opportunities-will continue to make missile technology very attractive for several countries of proliferation concern.

Barriers to Missile and Aircraft Proliferation

The spread of ballistic missiles around the world was greatly facilitated by the export in the 1970s and 1980s of Scud-B missiles from the former Soviet Union. With an increasing number of countries abiding by the MTCR, the number of potential missile suppliers has declined dramatically. Of the principal missile exporters, only North Korea has not agreed to comply. However, Ukraine poses future export concerns, since it contains much of the former Soviet missile production infrastructure, yet has not agreed to comply with the MTCR. Moreover, additional countries have learned to copy, modify, extend the range of, and produce their own missiles, and a small number have developed long-range systems—often in conjunction with space-launch programs and foreign technical assistance. Even so, MTCR constraints can slow the acquisition by developing countries of technologies associated with more advanced missiles--those having ranges in excess of 1,000 km or guidance errors of less than roughly 0.3 percent of their range.

Given the complex set of technologies and expertise used in advanced aircraft, especially high-performance jet engines, it remains virtually impossible for developing countries to acquire these systems without assistance. However, no internationally binding restrictions limit trade in combat aircraft, and such arms transfers continue to be used as an instrument of foreign policy. Moreover, overcapacity in Western defense industries, and the economic difficulties facing newly independent Soviet republics and Eastern European states, provide great incentive to develop arms export markets. Therefore, states can and probably will continue to acquire high-performance aircraft easily, without having to build them. Moreover, other options short of buying aircraft or building them from scratch are available to states wishing to acquire or mod@ combat aircraft, such as engaging in licensed production.[9]

If they have sufficient payload and range-and if they can be procured despite export controls—commercially available unmanned aerial vehicles can be adapted to deliver weapons of mass destruction without much difficulty. Developing cruise missiles requires greater technical capability. Even so, technologies for guidance, propulsion, and airframes are becoming increasingly accessible, particularly with the spread of licensed aircraft production arrangements to many parts of the world. The most difficult technical challenges to developing cruise missiles—propulsion and guidance-do not pose much of a hurdle today. The highest performance engines are not required for simple cruise missiles, and many sources are available for suitable engines. Guidance requirements can be met by satellite navigation services such as the U.S. Global Positioning System (GPS), possibly the Russian Glonass system, or commercial equivalents. Inexpensive, commercially available GPS receivers are becoming available to provide unprecedented navigational accuracy anywhere in the world. Although GPS receivers would have only limited utility to emerging missile powers for ballistic missile guidance, they could be used to reduce uncertainty in the launch location of mobile missiles.

Monitoring Delivery Vehicles

Although individual missiles can be very difficult to detect, a program to develop ballistic missiles is much more visible. Test firing and

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[9] The routes various states around the world have taken to develop defense industries, including aircraft industries, are discussed in U.S. Congress, Office of Technology Assessment, *Global Arms Trade*, OTA-ISC-460 (Washington, DC: U.S. Government Printing Office, June 1991).

launching ballistic missiles can be readily seen. Development of intermediate and long-range ballistic missiles requires extensive flight testing, making it particularly noticeable. Although states pursuing both military and civil space technology may wish to hide their military programs, civilian space-launch programs are usually considered a source of national prestige and proudly advertised.

Even a purely civilian space-launch program provides technology and know-how useful for ballistic missiles. The most important aspects of a missile capability for weapons of mass destruction-range and payload-can usually be inferred from a civil program. (A civil space-launch booster does not need to have high accuracy, but neither does a missile carrying weapons of mass destruction for use against populations.) On the other hand, certain attributes desired for military applications, such as reliable reentry vehicles, mobility, and ease of operation in the field, suggest distinct technical approaches for military and civil applications. Although solid-fueled boosters are in some ways more difficult to develop and build than liquid-fueled boosters, they are easier to use in mobile and time-urgent applications. Liquid-fueled boosters were the first used in military applications and are still more common. (The seemingly ubiquitous Scud missile and its modifications, such as were launched by Iraq against targets in Israel and Saudi Arabia, are liquid-fueled.)

Since combat aircraft are widely accepted as integral to the military forces even of developing countries, there is no reason to hide their existence. Individual planes, however, can be hidden. Moreover, modifications made to aircraft to carry weapons of mass destruction, or training given to pilots for their delivery, might be difficult to detect without intrusive inspections.

Of the three delivery systems, cruise missile development and testing will be the hardest to detect. Several types of unmanned aerial vehicles are being developed and marketed for civil purposes, and without inspection rights it will be difficult to discern whether such vehicles have been converted to military purposes. Therefore, monitoring of delivery systems capable of carrying weapons of mass destruction will continue to be an uncertain exercise, having most success with missiles and highly capable aircraft. Nevertheless, the risk posed by other delivery systems cannot be dismissed. The full range of delivery technology must be taken into account when evaluating a country's overall proliferation capabilities and behavior.