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Chinese Nuclear Testing and Warhead Development

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NOTE

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Chinese Nuclear Testing and Warhead Development

Summary

Several rationales may explain the development of Chinese nuclear weapons. These include *international* benefits (nuclear weapons may enhance security, influence, and prestige); *technology* (warhead development is constrained to certain paths by technological imperatives regardless of leadership or doctrinal preferences); *doctrine* (recent Chinese thinking may envision broadening nuclear weapons' role); and others. These rationales may have shifted in salience, with international benefits dominant early on and doctrine becoming more influential over time.

Data on China's nuclear test program reveal several points about China's approach to testing and goals for it. First, China conducted few tests compared to the other nuclear weapon states, and tested at a stable rate. Second, its highest-yield tests were conducted early in its test program, after which time the yield dropped sharply. Third, for tests with a yield of roughly 100 kilotons or less, yield dropped in 1972-1992. Thereafter, though, it increased, possibly in support of development of new warheads for new forces. Fourth, an analysis of the locations of Chinese underground tests, and the geology of those sites, casts little light on the purpose of tests prior to 1990 but strongly implies that the purpose of subsequent tests was weapons development.

China has reportedly embarked on a major program to upgrade its nuclear forces. Most analysts anticipate advances in missile accuracy, mobile ballistic missiles, and missile submarine forces, as well as deployment of multiple-warhead missiles. These advances hinge on warhead advances. In particular, increasing a warhead's so-called yield-to-weight ratio, i.e., the amount of explosive yield per unit of warhead weight, allows key improvements in China's nuclear forces that enable a role for these forces consistent with a doctrine more ambitious than minimum deterrence. Specifically, advances in yield-to-weight extend missile range, enable deployment of multiple warheads on a missile, facilitate submarine-launched ballistic missiles and mobile missiles, aid penetration of ballistic missile defenses, and contribute to accuracy. These advances together would make China's nuclear forces more survivable while increasing their offensive potential. China is likely to produce new warheads for these forces for some time, as well as to conduct maintenance and modification of existing warheads on an ongoing basis.

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This report provides information on Chinese nuclear warhead issues. It starts with some rationales for Chinese nuclear weaponry. It then describes China's warhead development program, focusing on the role of testing, and shows key opportunities in weapon systems made available by a single type of advance in warhead development. There follows a discussion of China's development of missiles and bombers, and of warhead production.

This report is based mainly on data from open, mainly U.S., sources. Unclassified research requires this approach because China releases very little official information on its nuclear program, less even than Russia. The Departments of Defense and Energy, and the Central Intelligence Agency, have reviewed this document and found it to contain no information they would classify. These agencies, of course, make no representation as to the accuracy of information derived from unofficial sources. Interpretations based on U.S. or Chinese classified information might differ from those presented here.

Rationales

Several possible rationales may explain the initial development of Chinese nuclear weapons and their current and prospective configuration, such as:

International security, influence, and prestige: Early motivations for China's weapons development program included U.S. threats in the 1950s to use nuclear weapons against China, the huge losses China suffered in the Korean War, U.S. support for Taiwan, and the growing Sino-Soviet rift. China's leaders, especially Chairman Mao Zedong, felt that China had to have nuclear weapons to be seen as a great power and to avoid being coerced by U.S. or Soviet nuclear or conventional threats. Motivations for China's current weapons development program include the many problems and potential threats China faces, against which more advanced nuclear weapons might prove useful. These include India, which has a modest nuclear program and has not signed the Nuclear Nonproliferation Treaty or the Comprehensive Test Ban Treaty; Taiwan, which is displaying increased signs of interest in formal independence from China and which China fears the United States might defend;[1] Russia, a former foe that appears to face a protracted period of instability; Japan, which is widely believed able to develop sophisticated nuclear weapons quickly; and the United States, which could block China on Taiwan and elsewhere and is developing theater and national missile defenses that might negate much of China's current nuclear force.

Technology: Technology constrains nuclear warheads to certain paths of development that are little influenced by doctrine or politics. Lewis and Xue, who have prepared the most thorough analysis of China's nuclear weapons development to date, note the many steps that China had to pursue to build its first bomb — uranium mining, extraction, enrichment, and fabrication; development of neutron initiators and high explosive components; design and fabrication of the weapon; and so on.[2] Any nation would have to follow similar steps to build a bomb on its own. While the decision to build the bomb was political, the main role of the political system after the decision was made seems to have been to facilitate technological progress, a role it played repeatedly. "In the nuclear world, China's real innovation was to tolerate and then mandate a reform of the political system in order to leave the hard choices to the nonpolitical specialists."[3] Indeed, the political system largely insulated the weapons program even from the Cultural Revolution, which turned much of China upside down.[4]

Doctrine: Initially, China's nuclear forces were very small in number, inaccurate, and vulnerable. As a result, they supported mainly a strategic doctrine of minimum deterrence, in which the threat of retaliating against a few cities in response to an attack might suffice to deter attack. Lewis and Hua believe that development of *any* doctrine is fairly recent: "There is no evidence that any overarching strategic doctrine informed Chairman Mao Zedong's decision to proceed with the strategic missile program in the mid-1950s. ... until the early 1980s, there were no scenarios, no detailed linkage of the weapons to foreign policy objectives, and no serious research."[5] Johnston argues that some Chinese analysts are now moving toward a doctrine of "limited deterrence," in which "nuclear weapons play a critical role in the deterrence of both conventional and nuclear wars as well as in escalation control ... if deterrence fails."[6] The new weapons currently being developed should be more accurate and less vulnerable than their predecessors, as discussed below, perhaps enabling China to adopt a more assertive doctrine than

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1 For a discussion of how U.S. theater missile defense might counter possible Chinese efforts to win back Taiwan, see Holly Porteous, "China's View of Strategic Weapons," *Jane's Intelligence Review*, March 1996: 136.

2 John Wilson Lewis and Xue Litai, *China Builds the Bomb*, Stanford, CA, Stanford University Press, 1988, p. 73-169.

3 Ibid., p. 232. For other examples of this protective role, see ibid., p. 118, 119, 130, 151, 224.

4 Ibid., p. 204.

5 John Wilson Lewis and Hua Di, "China's Ballistic Missile Programs: Technologies, Strategies, Goals," *International Security*, Fall 1992: 5-6.

6 Alastair Iain Johnston, "China's New `Old Thinking': The Concept of Limited Deterrence," *International Security*, Winter 1995/96: 12.

minimum deterrence. Those asserting the primacy of doctrine would view the new weapons as being developed in order to support a new doctrine.

Interservice competition: Branches of the armed forces in China, as anywhere else, compete for funds and do what they can to advance programs they favor. Politically, funding weapon programs from various branches of the armed forces is an easier course than choosing one program over another. Pursuing several alternative systems hedges against the failure in development of any single system. China's expanding economy and expanding geopolitical ambitions also facilitate this course. Interservice competition is a fairly recent phenomenon in China, dating only from the early 1980s. Before then, competition occurred among factions within the Chinese leadership rather than along interservice lines.[7]

It appears that these rationales shifted in salience over time. Initial pursuit of nuclear weapons flowed from a leadership decision based on an international rationale, the desire to have nuclear weapons and the power, security, and perhaps prestige they might offer. To implement this decision, the leadership supported and encouraged a growing team of scientists, engineers, and others as they followed the technological imperatives of an early weapons program. Later, China's continued pursuit of these imperatives led to more advanced warheads. As discussed on pages 7-10, these warheads opened the path to a greater variety of increasingly capable and specialized nuclear weapon systems. These systems, managed by different organizations within China's military, held the prospect of more flexible use and deterrence of a greater range of threats. Debates on doctrine now underway may lead to doctrine of increasing sophistication to govern the use of these systems and perhaps steer their development.

Nuclear Warhead Development And Testing Program

The course of Chinese nuclear warhead development has followed the same lines of technical development as the other nuclear weapon states, proceeding from atomic (fission) bombs to hydrogen (fission/fusion) bombs, to improved technical performance of these weapons. A key improvement is in the yield-to-weight ratio, that is, the amount of yield (explosive force) per unit of warhead weight. Other steps may include increased safety (resistance to accidental detonation) and increased security (resistance to unauthorized use).

According to Lewis and Xue, China conducted its first atomic bomb test in October 1964; a test in May 1966 proved the feasibility of a boosted fission weapon, a uranium device containing lithium-6; a December 1966 test examined thermonuclear explosion fundamentals in a device using uranium and lithium; and, in June 1967, China tested "a multistage thermonuclear bomb, a three-megaton device."[8] [9]

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[7] This sentence and the preceding one are based on discussions with Harlan Jencks, Lawrence Livermore National Laboratory, June 1997.

[8] Lewis and Xue, *China Builds the Bomb*, p. 197, 201.

[9] Modern nuclear weapons have two stages. In the first stage, the primary, a layer of

(continued...)

Afterwards, the Chinese conducted five more tests with yields between two and four megatons in the period 1968-1976 (along with a larger number of lower-yield tests), but shifted to work on smaller warheads.

A close review of data on testing, as presented in the four graphs at the end of this report, provides some insight into China's approach to testing and suggests that China's most recent test series was intended to develop lightweight warheads for new nuclear forces. The Central Intelligence Agency provided the dates and, in most cases, the yields of 45 Chinese nuclear tests. (See Appendix.) The CIA data are unclassified and are derived from open sources, mainly press reports. Graph 1 uses these data to plot number of tests per year. It shows that the number of tests was low — 45 compared to 1,030 for the United States, 715 for the former Soviet Union, 45 for Britain, and 210 for France.[10] China's rate of testing was stable. Of the 33 years from beginning to end of the test program, only three years had three or four tests (none had more), five years had no tests, and the remaining 25 years had one or two tests. The graph also shows that the rate of testing was highest in the beginning, when China was developing its earliest nuclear weapons; was lowest in the period 1981-1991; and picked up again in the five years, 1992-1996, when a CTB appeared plausible and then probable. But even in this latter period, the rate of testing was well within the historical rate.

Graph 2 plots each test by date and yield. Several points stand out. All tests of devices certainly yielding a megaton or more took place by 1976 and constituted six of the 21 Chinese tests to that point. Another three tests, one each in 1974, 1980, and 1992, may have had a yield of a megaton or more. Of the remaining 36 tests, only

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[9](...continued)
chemical explosive surrounds a hollow shell containing fissile uranium-235 or plutonium-239. Detonating the explosive creates an implosion wave that compresses the pit, making it go critical, fissioning (splitting) uranium or plutonium atoms, and releasing large amounts of energy as a nuclear explosion. Deuterium and tritium gases (isotopes of hydrogen) are inside the pit. The heat of the fission reaction makes them undergo fusion, releasing neutrons that enhance the fission reaction and "boost" explosive yield sharply. The secondary stage, containing lithium-6 deuteride and uranium, adds most of the yield. X-rays from the primary explosion flow inside a metal radiation case to the secondary. They transfer energy to compress and ignite the secondary, causing fusion of tritium and deuterium (released by lithium-6 deuteride) and fission of uranium. Weapons of this type are called thermonuclear because the high temperature of the primary drives the fusion reaction. Yield is measured in kilotons (one kiloton is equivalent to the explosive force of 1,000 tons of TNT) and megatons (millions of tons of TNT equivalent); the Hiroshima bomb had a yield of 15 kilotons.

[10] The U.S. figure is from U.S. Department of Energy. Nevada Operations Office. Office of External Affairs. *United States Nuclear Tests: July 1945 Through September 1992*. DOE/NV-209 (Rev. 15), December 1994, p. viii. This figure excludes 24 joint U.S.-U.K. tests, all of which were held at the Nevada Test Site, and excludes the bombs dropped on Hiroshima and Nagasaki. Figures for the other nations through 1995 are from Robert S. Norris and William Arkin, "Known Nuclear Tests Worldwide, 1945-1995," *Bulletin of the Atomic Scientists*, May/June 1996: 62. That source reports 209 French and 43 Chinese tests through the end of 1995. France conducted one test in January 1997; see Amy Barrett, "France Sets Off Underground Nuclear Blast in Pacific," Associated Press, January 27, 1996. China conducted tests in June and July 1997; see "Chronology of Nuclear Tests Conducted by China," Reuters, July 29, 1996.

six had an average yield[11] between 100 kilotons and one megaton. The open sources consulted do not provide the yield of one test. The remaining 29 tests had an average yield below 100 kilotons. This graph reinforces the idea that, once the Chinese developed megaton-range hydrogen bombs, their attention turned to smaller weapons, presumably with more yield-to-weight because of the advantages noted below.

Graph 3 plots each test with an average yield of 100 kilotons or less by date and yield. Graph 3 is presented because the scale of Graph 2, which goes up to four megatons, obscures any pattern in the tests yielding below about 100 kilotons, which are by far the most numerous. The main pattern revealed by Graph 3 is that most tests in this range had a yield around 20 kilotons in 1964-1971, 10 kilotons or less in 1972-1992, and well above 20 kilotons in 1993-1996. Recent tests below 100 kilotons may have been to develop warheads for SLBMs (submarine-launched ballistic missiles), mobile land-based ballistic missiles, or multiple-warhead missiles, whereas the earlier tests could have been to develop primaries for larger weapons. Physical data, however, provide no clues to the purpose of tests at the lowest yields. Possible explanations of those tests, drawing on the U.S. experience, include the following: tests of primaries for thermonuclear warheads; tests of warhead safety; tests to gather data on physical processes of a nuclear explosion; tests to develop or certify modifications to existing warheads; tests of tactical warheads; tests of the effects of nuclear explosions on military hardware; tests of warheads with simulated aged material to examine performance under end-of-life conditions; or even duds.

Graph 4 provides insight into the types of tests done and how they have changed over time, and corroborates the analysis in the next section regarding the purposes of recent tests. The graph plots each underground nuclear test at Lop Nor, in western China, the site of all Chinese tests, by date and location. (All Chinese tests after 1980 were held underground.) As detailed by Wallace and Tinker based on seismic data, and by Gupta based on seismic and satellite data, these tests cluster into two distinct areas.[12] A western area is in a mountainous region, and tests there are thought to be conducted in horizontal tunnels. An eastern area is flatter; tests there are thought to be conducted in vertical shafts.[13] Of the underground tests from 1968-1979, 3 of 4 were in the western area, vs. 3 of 6 tests conducted in the 1980s and 2 of 9 in the 1990s.

What can be inferred from the shift of tests from the western area (horizontal tests) to the eastern area (vertical tests)? In the U.S. case, tests in horizontal tunnels were immensely complex. Each test required excavating from solid rock a long entry tunnel (typically wide enough for a train), a chamber for the explosive device,

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[11] For purposes of this report, for tests having yield reported as a range, e.g., 20 to 40 kilotons, "average yield" is defined as the arithmetic mean of the high and low values of the range.

[12] Terry Wallace and Mark Tinker, "The Last Nuclear Weapons Test? A Brief Review of the Chinese Nuclear Weapons Program," *IRIS Newsletter*, Fall 1996: 9-11; and Vipin Gupta, "Locating Nuclear Explosions at the Chinese Test Site near Lop Nor," *Science and Global Security*, 1995, vol. 5, p. 205-244.

[13] Wallace and Tinker, "The Last Nuclear Weapons Test?": 11.

and miles of tunnels leading from the device to other chambers. These chambers held elaborate instrumentation, as well as samples of equipment and materials to check their response to the radiation from a nuclear explosion.[14] Tunnels were constructed to permit recovery of this experimental apparatus.[15] Excavation for U.S. horizontal tests sometimes took a year, working three shifts a day. Excavation for vertical tests was much simpler, typically taking 6 to 8 weeks.[16] The United States generally used horizontal tests to help design military equipment, such as reentry vehicles (which enclose a warhead and protect it as it falls to earth), conventional weaponry, or communications gear, so it can survive nuclear effects. Because of the cost, time, and difficulty of preparing for such tests, and the value of using a nuclear device whose characteristics were well known so as to aid calibration of the effects, the United States after 1963 almost never used horizontal tunnels for tests whose main purpose was other than effects,[17] preferring simpler vertical shafts instead. Presumably, given the differing requirements of excavation, horizontal tunnels were more elaborate than vertical shafts for the Chinese as well.

It is certainly possible that China used horizontal tests for multiple purposes. It conducted far fewer tests than did the United States, France, and Russia. As a corollary, it evidently tried to gain as much data from each test as possible. Horizontal tests permitted the gathering of much more data than did vertical tests because the former could have many tunnels leading away from the explosive, permitting more experiments and instruments. Each test may have supported weapons development, weapons effects, basic physics, etc.

It is less likely, though, that China used vertical tests for multiple purposes. These tests typically have a single shaft that leads from the surface to the explosive device. Instruments are placed near the device, and cables lead from them to recording equipment on the surface. These tests are not conducive to effects testing because it would be very difficult to build shafts leading from the device to hold samples (other than the main vertical shaft, which must be stemmed to prevent radiation from venting to the atmosphere) or to recover samples exposed to nuclear effects. At the same time, the progressive miniaturization of electronics surely increased the amount of information China could gain on the performance of a device. The instruments of the 1990s that could fit in a vertical shaft probably delivered more data than did several horizontal tunnels' worth of 1970s- or 1980s-vintage instruments. As a result, vertical shaft tests may have sufficed for sophisticated weapons development work in the 1990s but not earlier. Thus while the earlier horizontal tests may or may not have been for weapons design, the probability is high that the vertical tests of the 1990s were for that purpose. This evidence, combined with data on yield and on missile development, reinforces the

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[14] See U.S. Congress. Office of Technology Assessment. *The Containment of Underground Nuclear Explosions*. OTA-ISC-414. Washington, October 1989, p. 20-25, 41-46.

[15] Ibid., p. 41.

[16] Ibid., p. 18, 20.

[17] Of 49 post-1963 tunnel tests, 46 were for weapons effects, two were nuclear test detection experiments, and one was weapons related. Department of Energy, *United States Nuclear Tests, July 1945 Through September 1992*, p. 1-59.

idea that the thrust of the 1992-96 test series was to develop small, light warheads for its new nuclear forces.

Prospective Advances in Warhead Development And Their Value

China conducted its most recent test series from 1992 through 1996. During most of this time, no other nation was testing. China received widespread international criticism for these tests. Indeed, it declared that the test of July 1996 would be its last.[18] Why did China go to the effort, and suffer the criticism, of conducting these tests? What did China stand to gain?

Most analysts speculate that the Chinese will continue to make technical improvements to their warheads based on the results of their last test series. According to Norris, "It is logical to assume that China is traversing the same technical paths that have been pursued by the other nuclear powers, namely: miniaturization, better yield-to-weight ratios, improved missile accuracy, MIRVing of ballistic missiles [deploying multiple independently-targetable reentry vehicles, i.e., placing several warheads on one missile, with each warhead able to strike a separate target], and improved safety features."[19] According to Johnston, "we should expect China to continue the development of more accurate mobile inter-continental ballistic missiles (ICBMs), a larger submarine-launched ballistic missile (SLBM) capability, technologies that will improve the penetrability of warheads in the face of space and ground-based BMD [ballistic missile defense] ..."[20]

Many of these improvements, and the ones most directly linked to strategic goals, hinge on progress in developing nuclear warheads. China could well be unable to deploy the new missiles described below, or at best their military potential would be curtailed, without warhead advances. The main step in warhead development after attaining thermonuclear weapons is improving the yield-to-weight ratio so that a warhead can maintain a given yield with less weight and volume, or a warhead of a given weight and volume can have more yield, or a lower-yield warhead can have considerably less weight and volume, or some combination. According to Lewis and Xue, Chinese guidelines for warhead development in the 1970s included small size, and "in nuclear tests conducted in the 1990s, the Chinese sought to develop a new warhead with a much higher yield-to-weight ratio and with a capability of further miniaturization."[21] Developing smaller, lighter, lower-yield warheads with an improved yield-to-weight ratio typically requires testing, which probably explains why China conducted its recent test series despite sharp global

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[18] Seth Faison, "China Sets Off Nuclear Test, Then Announces Moratorium," *New York Times*, July 30, 1996: 3.

[19] Robert S. Norris, "French and Chinese Nuclear Weapon Testing," *Security Dialogue,* March 1996: 50.

[20] Johnston, "China's New `Old Thinking'": 6.

[21] John Wilson Lewis and Xue Litai, *China's Strategic Seapower: The Politics of Force Modernization in the Nuclear Age*, Stanford, CA, Stanford University Press, 1994, p. 177.

opposition. This section explains why yield-to-weight is so important, and thus why the recent test series was so important, by showing how progress in this area permits more favorable design tradeoffs in many areas of high strategic value. Without China's final test series, most of these advances might well have been foreclosed.

Increased yield-to-weight extends missile range. There is little information on the tradeoff between warhead weight and missile range for Chinese systems. A study on the U.S. Trident missiles that examines such tradeoffs in detail, however, provides insight. "For the `standard' (unmodified) [Trident II] missile at a nominal throw-weight of 2700 kg, the decrease in range for each incremental kilogram of throw-weight is about 2.0 n.m."[22] The study further notes a "rule-of-thumb that the total RV payload of a U.S. booster is roughly one-half of throw-weight."[23] Increasing yield-to-weight reduces weight for a given yield, which thus increases range.

Applying this analysis to Chinese missiles, lighter, smaller warheads enable an SLBM of a given size (constrained by the volume of a submarine's missile launch tube) to fly farther. This increases the ocean area from which a submarine can strike its targets, which increases the fraction of a submarine's patrol time it is within range of targets and reduces submarine vulnerability to open-ocean detection, and enables it to strike more distant targets. Lighter, smaller warheads enable mobile land-based ballistic missiles to be smaller, which allows the transporter to be smaller and lighter, and thus to disperse over a wider area, reducing vulnerability. Moreover, a smaller transporter can be camouflaged or hidden more easily. While missile characteristics (energy content of the propellant, missile weight, etc.) are the main contributors to missile range, reducing warhead weight increases range for any missile.

Increased yield-to-weight enables MIRVing. MIRVs are a force multiplier because one MIRVed missile can strike several targets. This is especially important for SLBMs; if each missile carries, say, four warheads instead of one, then one submarine can do the work of four, saving a fleet the cost of many missiles and submarines. MIRVs are also useful for saturating and penetrating ballistic missile defenses. Splitting a missile's payload into multiple warheads rather than concentrating it in a single large warhead reduces the missile's aggregate yield. That proves not to be a serious concern, however, because lower-yield warheads can destroy unhardened targets, such as infrastructure, military bases, ports, troop

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22 John Harvey and Stefan Michalowski, *Nuclear Weapons Safety and Trident: Issues and Options*, Stanford, CA, Stanford University, Center for international Security and Arms Control, 1993, p. 59.

23 Ibid., p. 42. Note the following definitions: An RV, or reentry vehicle, is the aerodynamically shaped shell (usually conical with a rounded nosetip) containing the warhead and protecting it as it passes through the atmosphere. Payload consists of RVs and devices for helping RVs penetrate ballistic missile defenses. Throw weight is payload plus a post-boost vehicle, a device for steering each of several warheads carried by a single missile to multiple targets. U.S. Department of State. Bureau of Public Affairs. *SALT II Agreement*. Department of State Publication 8984, General Foreign Policy Series 316. Washington, U.S. Govt., Print. Off., June 1979, p. 53-54.

concentrations, and key parts of cities, if delivered with reasonable accuracy.[24] (As technology progresses, moderate-yield MIRVed warheads can be developed that can destroy hardened targets like missile silos if delivered with high accuracy.) To fit several warheads on a missile requires a substantial advance in yield-to-weight, mainly to reduce warhead weight and volume and also to regain some of the yield lost by MIRVing. Techniques to improve yield-to-weight, such as miniaturization of components, increased design efficiency, lighter materials, and minimization of material used, are thus essential to MIRVing.

Increased yield-to-weight facilitates SLBMs. Various cost and engineering tradeoffs constrain the diameter of a submarine's hull. This diameter, in turn, constrains the length and diameter of an SLBM. The missile designer's challenge is to fit the warhead, propulsion, guidance, and other missile functions within a package of a fixed size. The warhead's diameter must be small enough so that, when enclosed in its reentry vehicle, it will fit atop the missile. Moreover, it is safer to use solid fuel in the missile (although early Soviet SLBMs were liquid-fueled); storing liquid fuel in a submarine is hazardous. Yet compared to liquid fuel, solid fuel provides less range, less payload, or some combination for a given volume.[25] A heavy warhead at best would shorten missile range, and at worst would be too heavy for the missile to lift. So, according to Lewis and Xue, "The three critical technologies in building [China's first] SLBM were solid propulsion, a compatible missile guidance set, and a small, potent warhead." The Chinese were at first unable to miniaturize the warhead, but found design approaches to do so, at which point "the door was opened for the Chinese to reduce the size of their nuclear weapons."[26]

Increased yield-to-weight facilitates mobile ballistic missiles. A continuing goal of China's strategic nuclear program is to improve survivability. To this end, China has moved from its initial force of large liquid-fueled ballistic missiles that had to be erected and fueled before launch, to underground silos, missile submarines, and solid-fueled mobile ballistic missiles. A smaller, lighter warhead can be carried by a smaller missile. In turn, the smaller the missile, the more roads and bridges it can go over, the more places it can hide, and the harder it will be to detect.

Increased yield-to-weight facilitates penetration of ballistic missile defenses. Penetration aids, or penaids, are carried by ballistic missiles to be dispersed in space or in the atmosphere. Penaids include lightweight decoys, heavier decoys that better mimic actual warheads, and clouds of radar-reflecting material dispersed in space. Johnston, Porteous, Lewis and Hua, and others hold that China is concerned about ballistic missile defenses;[27] penaids would address these concerns. Penaids are typic

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[24] MIRVed warheads can also be used to attack hardened targets like ICBM silos, but that mission requires high accuracy that, for now, the Chinese do not evidently possess, as well as many more warheads. (Of course, even a successful attack on ICBMs would still leave at-sea SSBNs available for retaliation.)

[25] Discussion between the author and Lawrence Livermore National Laboratory staff, January 10, 1997.

[26] Lewis and Xue, *China's Strategic Seapower*, p. 176-178.

[27] Johnston, "China's New `Old Thinking'": 25-26; Porteous, "China's View of Strategic (continued...)

ally deployed on the front end of a missile; therefore, reducing warhead size and weight frees volume and carrying capacity for penaids.

Increased yield-to-weight contributes to accuracy: While a missile's guidance system is the main determinant of missile accuracy, and other factors such as RV design and missile control also play roles, the warhead itself can affect accuracy. Harvey and Michalowski present a detailed technical explanation.[28] In essence, the lower the cross-sectional area perpendicular to the axis of flight of the (conical) RV, the less the RV will slow down in the atmosphere, reducing the time during which atmospheric conditions can knock the RV off course. Smaller warhead diameter permits a smaller RV diameter. Also, a shorter warhead permits a reduction in the diameter of the RV's base. (Shortening a warhead beyond a certain point, however, causes various problems.)

Missile And Bomber Programs

Chinese leaders have often debated which missiles to build, which to accelerate or cancel, what their range (i.e., targets) and other characteristics should be, and more. A requirement for a missile of a given range, say, or for an SLBM, would lead to a requirement for a warhead to arm it. In some cases, China evidently uses one type of warhead, perhaps with modifications, on several types of missiles; for example, China's general design plans are said to call for five missiles — the JL-1 and JL-2 SLBMs and the DF-21, DF-31, and DF-41 land-based ballistic missiles — to use virtually the same warhead.[29] In other cases, a warhead type is intended for a single missile type.[30] Conversely, the state of warhead development provides both constraints on and opportunities for new missiles. For example, China's first SLBM required a warhead with substantially less weight and volume than existing warheads had. At the same time, technical progress has opened the way for improved warheads that have permitted new missiles.[31]

China's strategic missiles have followed a rather straightforward technical progression, increasing range, payload, and survivability, and moving from liquid to solid fuel. China has now reportedly embarked on a major program to upgrade its nuclear forces, with the following systems reported to be under development.[32] Note that some missile advances exploit increases in warhead yield-to-weight.

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[27](...continued)
Weapons": 135-136; and Lewis and Hua, "China's Ballistic Missile Programs": 21.

[28] Harvey and Michalowski, *Nuclear Weapons Safety and Trident*, p. 40-42.

[29] Lewis and Hua, "China's Ballistic Missile Programs": 30.

[30] Robert Norris, Andrew Burrows, and Richard Fieldhouse, *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*. Boulder, CO, Westview Press, 1994, p. 358.

[31] Lewis and Xue, *China's Strategic Seapower*, p. 177-178.

[32] For a detailed description of Chinese missiles that are deployed or under development, see U.S. Library of Congress. Congressional Research Service. *China: Ballistic and Cruise Missiles*. Report 97-391 F, March 21, 1997, 15 p., by Shirley Kan and Robert Shuey.

Land-based ballistic missiles: Goals include increased survivability, as well as "general improvements in accuracy, range, guidance, and control. Much work is proceeding to have a next generation of missiles with solid fuel that are mobile and have multiple warheads."[33] China is said to be developing two mobile missiles, the DF-31, a three-stage, solid-fuel missile able to carry 700 kg to a range of 8,000 km, and the DF-41, also with three stages and solid fuel, with a range of 12,000 km.[34]

Strategic submarines and their missiles: The Office of Naval Intelligence, in reviewing the Chinese submarine program, makes the following points.[35] There is only one XIA class SSBN (nuclear-powered ballistic missile submarine), and its design "has fallen short of expectations." China is designing a new SSBN, the Type 094, which is "to be constructed early in the next century." The Office of Naval Intelligence projects no 094s by 2000, one by 2005, and three by 2010. The expectation is that the 094 will be "a dramatic improvement" over the XIA and will carry 16 new JL-2 SLBMs. That missile, with a range exceeding 4,000 nmi (7400 km), "will allow Chinese SSBNs to target portions of the United States for the first time from operating areas located near the Chinese coast." The JL-2, according to Norris et al., is said to be a three-stage solid-fueled missile derived from the DF-31 with a payload of 700 kg.[36] Note that a small, light warhead is essential for the JL-2 to have this long range.

Cruise missiles: Porteous states that China is developing "a long-range cruise missile for which the Chinese are said to have imported top Russian technicians," and that this missile "may carry a nuclear warhead."[37] Kan and Shuey are more circumspect in their evaluation, noting that "China apparently does not have land attack cruise missiles, but may develop one in the future."[38] They note reports that China reached an agreement with Russia in 1996 to buy two destroyers that would be equipped with anti-ship cruise missiles, and that these missiles can carry a nuclear or conventional warhead to a range of 160 km.[39]

The unclassified literature indicates that China has not MIRVed any of its missiles and, by one report, is unlikely to do so until about 2010.[40] At the same time, this is a likely goal as a way to increase the number of deployed warheads economically. It is also a normal progression for missile programs; all strategic

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[33] Norris et al., *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, p. 372.

[34] Ibid.

[35] U.S. Navy. Office of Naval Intelligence. *Worldwide Submarine Challenges.* February 1997, p. 22-23.

[36] Norris et al., *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, p. 370.

[37] Porteous, "China's View of Strategic Weapons": 134-135.

[38] Kan and Shuey, *China: Ballistic and Cruise Missiles*, p. 9.

[39] Ibid., p. 11.

[40] Robert Norris and William Arkin, "British, French, and Chinese Nuclear Forces," *Bulletin of the Atomic Scientists*, November/December 1996: 67.

ballistic missiles currently deployed by the other four nuclear powers, excepting the Russian SS-25 ICBM, are MIRVed.[41] The payload of the DF-31/ JL-2, reported to be 700 kg (1540 lb.),[42] should suffice for MIRVing even without the most advanced missile technology. For example, the Poseidon, the first U.S. MIRVed SLBM, first deployed in 1971, carried ten warheads[43] with a throw weight variously estimated at 2,000 to 3,000 lb.[44]

If China's test series did not suffice to develop warheads light enough to enable MIRVing, but came close, other technical avenues may be available to allow MIRVing with the best available warheads. Missile carrying capacity may be increased by using more energetic fuels and by lightening the guidance system, missile body, or other components, thereby increasing the missile's energy-to-weight ratio. Missile accuracy can be improved by advanced guidance systems. Improved accuracy is critical for attacking targets hardened against nuclear weapon effects, notably missile silos, but is also important for enabling lower-yield warheads to destroy unhardened targets. As such, improving accuracy reduces the yield (and weight) of a warhead needed to destroy a specified target.

China is widely reported to be seeking assistance in missile technology from the former Soviet Union. According to Henry Sokolski, "Under a [1994] five-year defense cooperation agreement with China, Russia sent solid rocket fuel technology, mobile missile know-how, large liquid rocket engines, missile guidance and multiple warhead hardware and hundreds of Russian missile experts to help China develop its own version of Russia's highly accurate, intercontinental SS-25 missile."[45] The *Washington Times* reported in 1996, "The United States has strongly protested China's efforts to buy SS-18 [ICBM] missile technology from Russia and Ukraine that would increase Beijing's capability to threaten American cities with nuclear

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41 See ibid., p. 64-65, for British and French nuclear forces. See also Norris and Arkin, "Estimated Russian [Nuclear] Stockpile, End of 1996, *Bulletin of the Atomic Scientists*, May/June 1997: 63; and Norris and Arkin, "U.S. Strategic Nuclear Forces, End of 1996," *Bulletin of the Atomic Scientists*, January/February 1997: 70.

42 Lewis and Hua, "China's Ballistic Missile Programs," p. 11.

43 U.S. Department of Defense. *Soviet Military Power, 1990.* Washington, U.S. Govt. Print. Off., 1990, p. 55. Other sources indicate the missile could carry up to 14 warheads.

44 The 2,000-lb. figure is from *The Military Balance, 1977-1978*, London, International Institute for Strategic Studies, 1977, p. 77; the 3,000-lb. figure is from *The Military Balance, 1985-1986*, London, International Institute for Strategic Studies, 1985, p. 158. Payload includes RVs and penetration aids (devices to help RVs penetrate ballistic missile defenses). Throw weight includes payload plus a post-boost vehicle, in essence a final missile stage that carries RVs and penetration aids. The post-boost vehicle has a guidance system, fuel, and thrust devices to change the flight path in order to dispense RVs toward different targets. Single-RV missiles may used post-boost vehicles to increase accuracy. U.S. Department of State. Bureau of Public Affairs. *SALT II Agreement*. Washington, U.S. Govt. Print. Off., 1979, p. 54-54.

45 Henry Sokolski, "Reckless Russian Exports," *Space News*, June 23-29, 1997: 15, as corrected in *Space News*, June 30-July 6, 1997: 4.

attack, Defense Secretary William J. Perry said."[46] The *New York Times* reported the next day that U.S. officials "said they had press reports and intelligence information that China was shopping around for the massive, multiple-warhead SS-18's, with Beijing seeking to purchase the missiles and components, purportedly for its civilian space-launching program, from cash-starved Russian and Ukrainian companies."[47] A 1997 press report stated, "Belarus is assisting China's development of a new mobile intercontinental ballistic missile by providing key launcher-related technology and equipment."[48] Russia is reportedly helping China develop a land-attack cruise missile that would have more precise guidance by using signals from Russia's Global Navigation Satellite System.[49] China's civilian space program is also pursuing technologies that could be applied to ballistic missiles, such as Western or redesigned guidance components[50] and the ability to have one rocket place multiple satellites into orbit.[51]

China's bomber force has, by all accounts, the lowest priority of China's nuclear forces. It is widely seen as outdated and having questionable survivability. Apparently, very little is being done to upgrade it for a nuclear role.[52] Many U.S. analyses of China's nuclear forces ignore it.[53] Chinese short-range missiles could deliver nuclear weapons in tactical situations, avoiding the need to use bombers for that purpose.

The philosophy of giving lowest priority to bomber development presumably carries over to bomb development as well. Older bombs intended to be detonated in the air or at the instant of contact with the ground are easier to design than missile warheads, requiring neither the ability of a missile warhead to survive the stresses of reentry, nor a rugged case to survive ground impact or penetration, nor special efforts to maximize yield-to-weight. Adapting bombs of that type for use on new bombers might require changing attachment hardware and communication links with the aircraft, not nuclear testing. Even some advanced bomb technologies, such as modifying bombs for earth penetration, may not require nuclear testing, as the U.S.

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46 Bill Gertz, "Russia, Ukraine Get Stern Missile Warning," *Washington Times,* May 21, 1996: 1.

47 Steven Erlanger, "U.S. Warns 3 Nations Against Sale of Soviet Missile Technology," *New York Times,* May 22, 1996: 4.

48 Bill Gertz, "Missile-Related Technology Sold to Beijing by Belarus," *Washington Times,* June 12, 1997: 9.

49 Kan and Shuey, *China: Ballistic and Cruise Missiles*, p. 15.

50 Craig Covault, "Chinese Long March [missile] Faces Crucial Return to Flight," *Aviation Week and Space Technology*, March 24, 1997: 24.

51 Liu Hong, "Long March 3B Chief Designer Interviewed," Xinhua (Beijing), August 21, 1997.

52 See Robert Norris and William Arkin, "NRDC Nuclear Notebook: British, French, and Chinese Nuclear Forces," *Bulletin of the Atomic Scientists*, November/December 1996: 67; and Paul Jackson et al., ed., *Jane's All the World's Aircraft, 1996-97*, Coulsdon, Surrey, Jane's Information Group Limited, 1996, p. 49-70 and 425.

53 Regarding the latter point, see, for example, Johnston, "China's New `Old Thinking'" and Lewis and Hua, "China's Ballistic Missile Programs."

B61-11 bomb demonstrates.[54] It seems most unlikely, then, that the Chinese would have dedicated recent nuclear tests solely to improving bombs.

Production

The development of new missiles, the last nuclear test series, and the evident development of new warheads, taken together, strongly imply that China will produce warheads of these newly developed designs for some time. What, after all, would be the point of developing new missiles and testing warheads of new designs if the latter were not going to be used to arm the former? Numbers to be built are highly speculative. Some sense of scale may be inferred from an estimate by Norris et al. that China has perhaps 300 deployed nuclear weapons and 150 tactical nuclear weapons that are available but not deployed, and that the stockpile could actually be two or three times larger.[55] A build of some hundreds of new warheads thus seems plausible. China, with two sets of nuclear production facilities,[56] appears to have ample production capacity for a build of this size or larger, especially if, as seems likely given the prospective schedule on which new missiles might be deployed, production is spread out over a decade or more. Fissile material supply can be a bottleneck for weapons production, yet China is thought to have ample supplies for a build of this size.[57]

Any modification of existing warheads would also require production work. Moreover, as with the other nuclear weapon states, continuing maintenance of warheads seems essential; maintenance requires production-type operations such as warhead disassembly; development and fabrication of new components; replacement of old components with new ones; and reassembly. China thus seems likely to carry out various types of production activity on an ongoing basis.

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[54] See Matthew Wald, "U.S. Refits a Nuclear Bomb to Destroy Enemy Bunkers," *New York Times*, May 31, 1997: 1.

[55] Norris et al., *Nuclear Weapons Databook, Vol. V*, p. 358.

[56] Norris et al., *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, p. 349-350.

[57] David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*. Oxford, Oxford University Press and Stockholm International Peace Research Institute, 1997, p. 76-77.

Conclusion

In 1996, China concluded what it said were its final nuclear tests. The main purpose of this test series was evidently to develop smaller, lighter new warheads with an increased yield-to-weight ratio. These warheads offer advantages that are crucial for China's nuclear forces, such as facilitating land-mobile ballistic missiles and a more potent missile submarine force, and increasing survivability. These warheads can be expected to arm a new generation of missiles now under development or in production. Production of missiles and warheads can be expected to continue for some years.

APPENDIX

This Appendix includes sources and notes (this page) for Table 1, "Data on Chinese Nuclear Tests, 1964-1996"; Table 1; Table 2, "Chinese Nuclear Tests and Yields"; Graphs 1-3, which plot data from Table 1; and Graph 4.

Source column:

C: U.S. Central Intelligence Agency. Chinese Nuclear Tests and Yields, prepared December 23, 1996, 1 p., unclassified. (Reproduced as Table 2.)

G: Vipin Gupta, "Locating Nuclear Explosions at the Chinese Nuclear Test Site near Lop Nor," *Science and Global Security*, 1995, vol. 5, p. 208.

N: Robert Norris, Andrew Burrows, and Richard Fieldhouse, *Nuclear Weapons Databook, Vol. V, British, French, and Chinese Nuclear Weapons*. Boulder, CO, Westview, 1994, p. 421.

*: The CIA report labeled the yield of this test as "low." For purposes of graphing, it is here assigned a yield of 10 kilotons.

?: None of the above sources contained data for this test.

Notes:

Some yield estimates are presented in the above sources as having a range, e.g., 20 to 40 kilotons; others are shown as a single value. Where only one value is presented in the table, it is shown in the "low" column. Values for a test in the "low" and "high" columns indicate a range. As the accompanying graphs are unable to show both ranges and points, they use "average" (mean) values to transform a range to a point. For the five tests that the CIA report listed as less than 20 kilotons, the figure used in the graphs is 10 kilotons (the mean of zero and 20). They are shown in the table as having a low yield of zero kilotons and a high of 20.

While yields sometimes differ between the three sources used here (and others), this table does not average the yields reported for a given test. Rather, it uses CIA data for the 35 tests where it was provided. For eight of the remaining ten tests, this table uses data from Gupta, which is based on seismic data. For one test, Norris et al. had the only data. For one test, no data were available.

Table 1: Data on Chinese Nuclear Tests, 1964-1996							
					............Yield, kilotons.............		
Test no.	Year	Mo.	Day	Source	Average	Low	High
1	1964	10	16	C	20	20	
2	1965	5	14	C	30	20	40
3	1966	5	9	C	200	200	
4	1966	10	27	C	20	20	
5	1966	12	28	C	300	300	
6	1967	6	17	C	3000	3000	
7	1967	12	24	C	20	15	25
8	1968	12	27	C	3000	3000	
9	1969	9	22	C	25	25	
10	1969	9	29	C	3000	3000	
11	1970	10	14	C	3000	3000	
12	1971	11	18	C	20	20	
13	1972	1	7	C	10	0	20
14	1972	3	18	C	110	20	200
15	1973	6	27	C	2500	2000	3000
16	1974	6	17	C	600	200	1000
17	1975	10	26	C	10	0	20
18	1976	1	23	*	10	10	
19	1976	9	26	C	110	20	200
20	1976	10	17	G	2.6	2.6	
21	1976	11	17	C	4000	4000	
22	1977	9	17	C	10	0	20
23	1978	3	15	C	10	0	20
24	1978	10	14	G	3.4	3.4	
25	1978	12	14	C	10	0	20
26	1979	9	13	?			
27	1980	10	16	C	600	200	1000
28	1982	10	5	N	9	3	15
29	1983	5	4	G	1	1	
30	1983	10	6	G	14.9	14.9	
31	1984	10	3	G	9.1	9.1	
32	1984	12	19	G	1.3	1.3	
33	1987	6	5	G	250	250	
34	1988	9	28	C	1.5	1.5	
35	1990	5	26	G	11.5	11.5	
36	1990	8	16	G	189	189	
37	1992	5	21	C	1250	700	1800
38	1992	9	25	C	15	15	
39	1993	10	5	C	30	20	40
40	1994	6	10	C	25	10	40
41	1994	10	7	C	95	40	150
42	1995	5	15	C	95	40	150
43	1995	8	17	C	50	20	80
44	96	6	8	C	50	20	80
45	1996	7	29	C	3	1	5

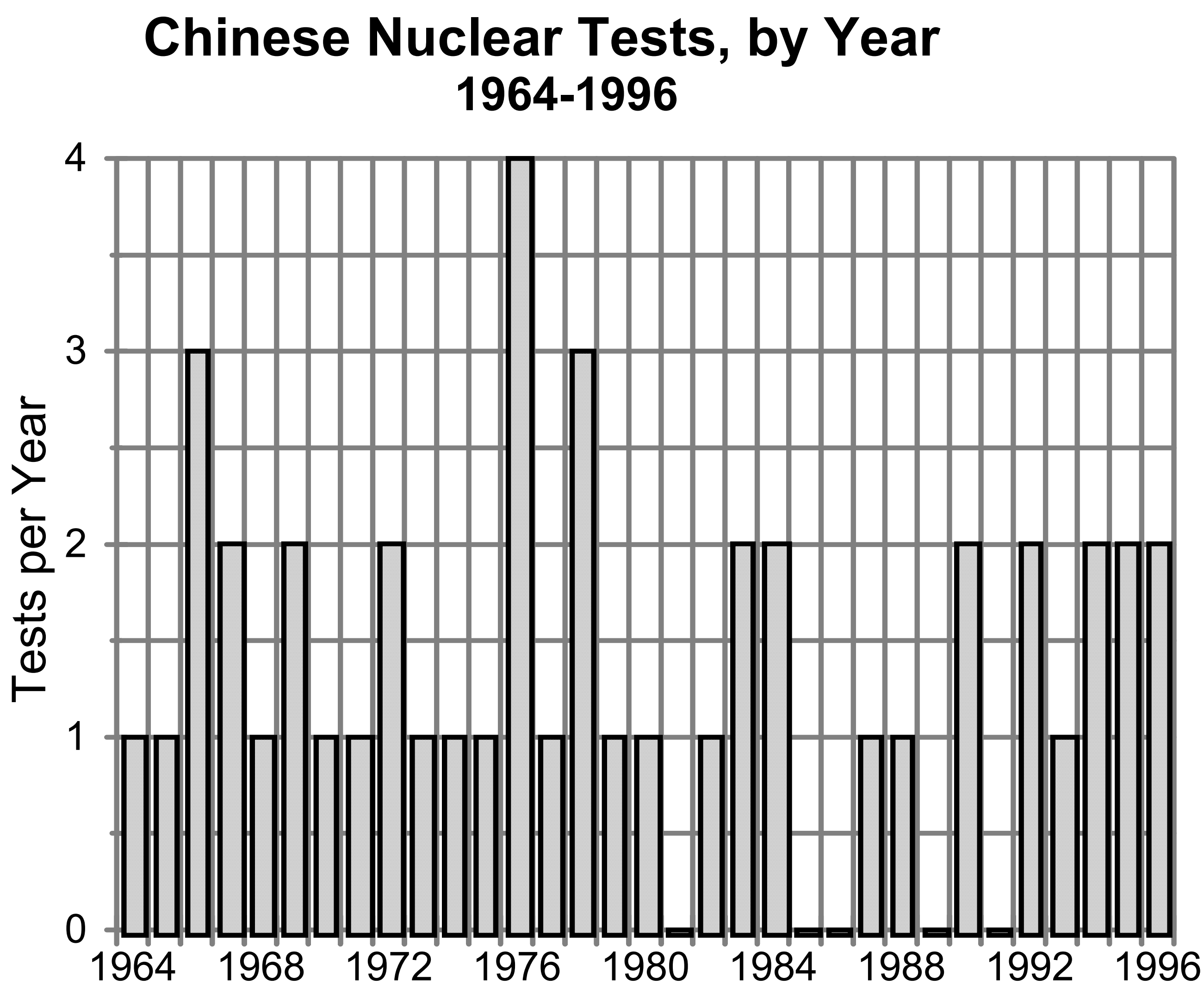
Sources and Notes: See page 16.

Table 2: Chinese Nuclear Tests and Yields

Test Number	Date	Yield	Test Number	Date	Yield
1	10/16/64	20 KT	24	10/14/78	?
2	05/14/65	20-40 KT	25	12/14/78	<20 KT
3	05/09/65	200 KT	26	09/13/79	?
4	10/27/66	20 KT	27	10/16/80	20 KT-1 MT
5	12/28/66	300 KT	28	10/05/82	?
6	06/17/67	3 MT	29	05/04/83	?
7	12/24/67	15-25 KT	30	10/06/83	?
8	12/27/68	3 MT	31	10/03/84	?
9	09/22/69	25 KT	32	12/19/84	?
10	09/29/69	3 MT	33	06/05/87	?
11	10/14/70	3 MT	34	09/29/88	1-2 KT
12	11/18/71	20 KT	35	05/26/90	?
13	01/07/72	<20 KT	36	08/16/90	?
14	03/18/72	20-200 KT	37	05/21/92	700KT-1.8MT
15	06/27/73	2-3 MT	38	09/25/92	15 KT
16	06/17/74	200 KT-1 MT	39	10/05/93	20-40 KT
17	10/26/75	<20KT	40	06/10/94	10-40 KT
18	01/23/76	LOW	41	10/07/94	40-150 KT
19	09/26/76	20-200 KT	42	05/15/95	40-150 KT
20	10/17/76	LOW	43	08/17/95	20-80 KT
21	11/17/76	4MT	44	06/08/96	20-80 KT
22	09/17/77	<20 KT	45	07/29/96	1-5 KT
23	03/15/78	<20KT			

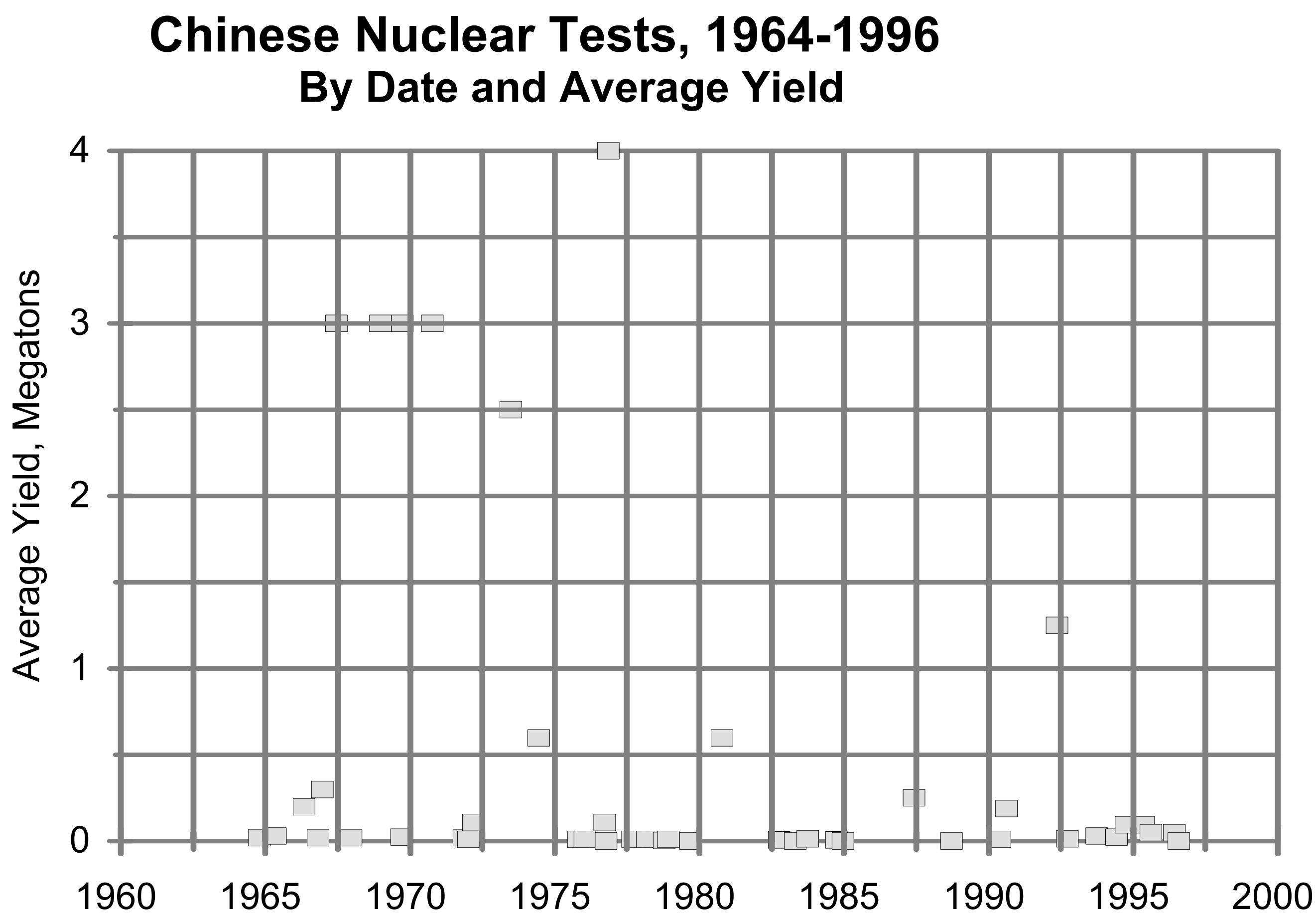
Source: Central Intelligence Agency, December 23, 1996. The data are unclassified and are derived from open sources, mainly press reports.

Graph 1



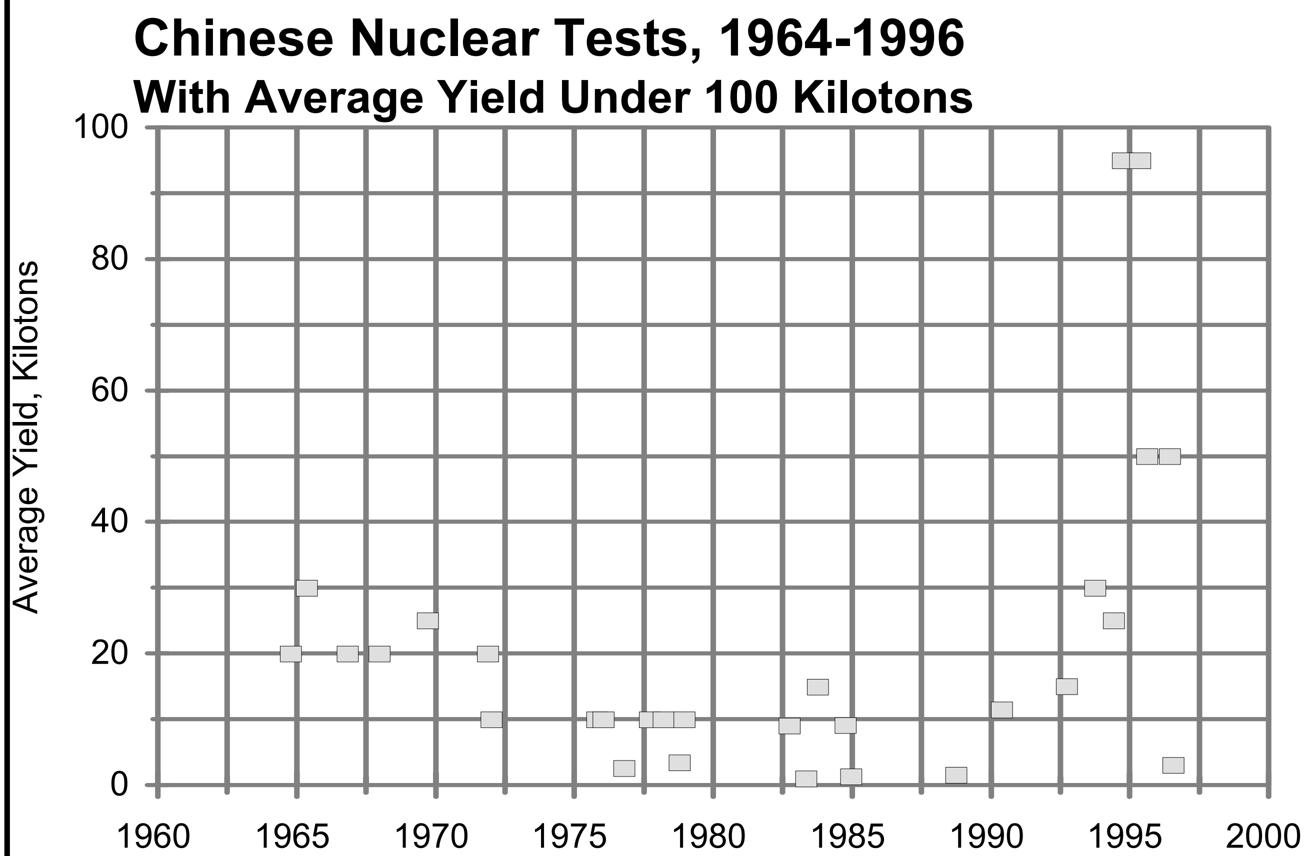
Source and notes: See Appendix

Graph 2



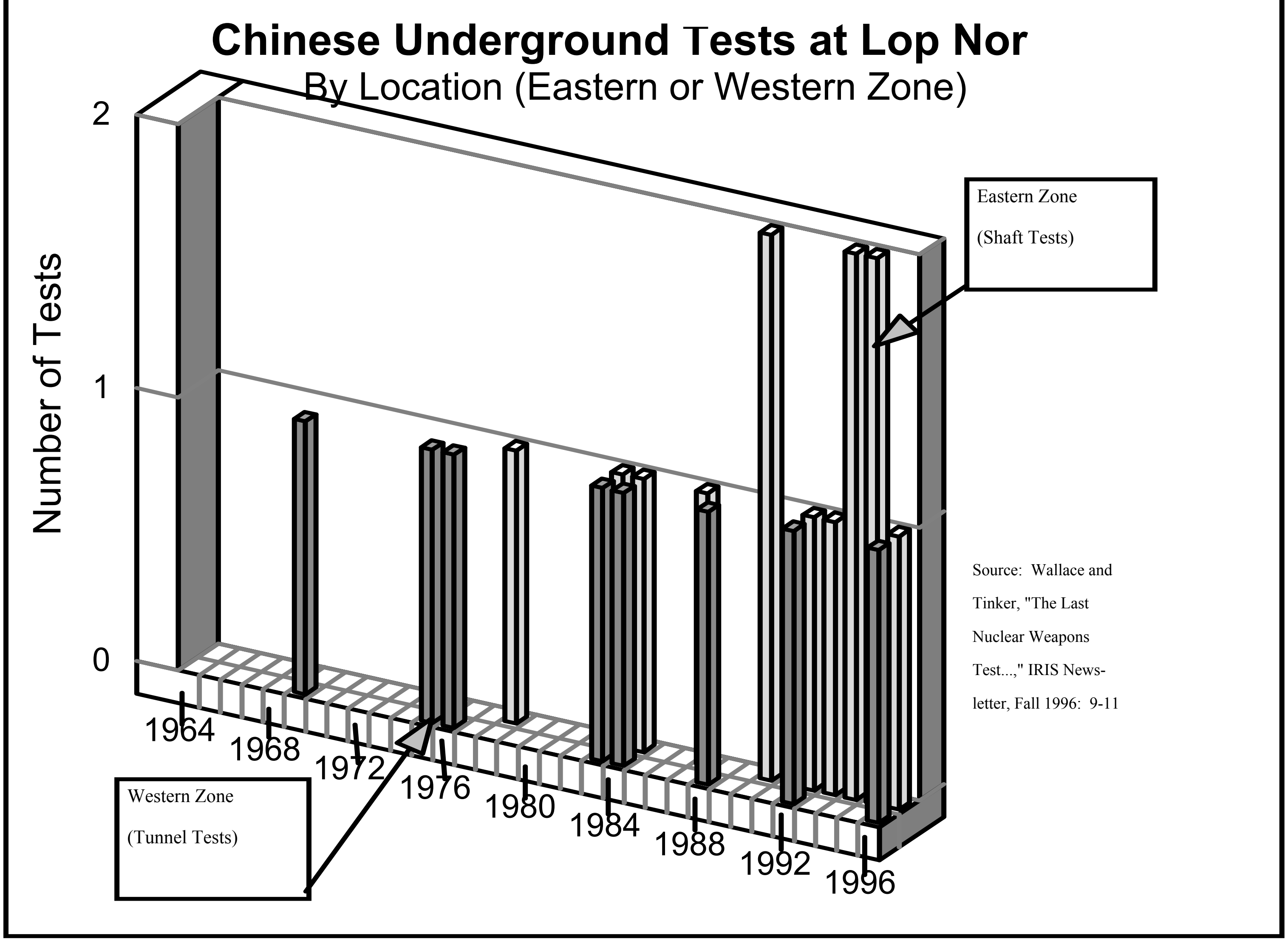
Source and notes: See Appendix

Graph 3



Source and notes: See Appendix

Graph 4


Chinese Underground Tests at Lop Nor
By Location (Eastern or Western Zone)
Number of Tests
2
1
0
1964
1968
1972
1976
1980
1984
1988
1992
1996
Eastern Zone
(Shaft Tests)
Western Zone
(Tunnel Tests)
Source: Wallace and Tinker, "The Last Nuclear Weapons Test...," IRIS News-letter, Fall 1996: 9-11