5 NUCLEAR LATENCY AND NUCLEAR PROLIFERATION

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HOW QUICKLY COULD INDIVIDUAL GOVERNMENTS, starting from different levels of nuclear-related expertise and technology, develop a nuclear weapon if they chose to do so? This question—which I will call the "nuclear latency" question—is both exceedingly important and poorly understood. It is important because an accurate understanding of both underlying state capabilities and the time needed to utilize such capabilities is necessary to analyze a wide set of nuclear policy issues: for example, dealing with the Iran nuclear crisis (how quickly could Tehran make a weapon from its stockpile of low–enriched uranium?); understanding the relationship between the spread of civilian nuclear power and the spread of nuclear weapons capability (will new civilian programs make breakout to military programs easier and more likely?); evaluating potential NPT reforms (what would be the effects of lengthening the ninety-day notice in the Article X withdrawal clause?); or assessing the stability of a world without nuclear weapons (could disarmed states rearm in five days, five weeks, five months, or five years?). Despite widespread discussion of these policy issues, however, a set of mirror-image analytic failures has limited our ability to make clear predictions about nuclear latency and proliferation: Political scientists working on these subjects have often failed to examine basic technical factors regarding the nuclear fuel cycle that strongly influence how quickly states can get the bomb; the more technical literature about nuclear latency has similarly often failed to examine the political factors that strongly influence the ability of a government to develop nuclear weapons.

This chapter is both a conceptual minesweeping exercise and a modest effort to suggest a better way forward. It has four main parts. First, I briefly present examples of how some journalists, diplomats, and scholars have misunderstood the nature of nuclear latency in their interpretations of IAEA reports, leading to exaggerations concerning the number of states that currently could build nuclear weapons in a short period of time. Second, I review and critique the political science literature on "nuclear capability" and "nuclear latency." Even the most sophisticated political science studies on this subject have too often used misleading measures of the key variables involved in nuclear technology, focusing on broad measures of industrial capability and nuclear research reactor experience and not on the specific fuel cycle technologies and facilities needed to make the fissile materials required for a nuclear weapon. This has led some political scientists, quite mistakenly in my view, to denigrate the NPT regime, arguing that efforts to restrict the spread of sensitive nuclear technology have failed in the past and that further restrictions in the future are likely to be ineffective or even counterproductive. Third, I review and critique leading examples from the technical literature on nuclear latency. These studies have usefully focused on how long it has taken individual states to develop highly enriched uranium (HEU) or weapons-grade plutonium but have unfortunately too often left out of their analyses the political factors that accelerate or constrain such fissile material development. These technical studies have also usefully included estimates of how long it might take a state to develop one or more nuclear weapons once it has the necessary fissile material and the political leadership has made a decision to seek a nuclear bomb. However, they have ignored the strategic and domestic factors that can influence the urgency of a leader's demand for nuclear weapons and the domestic political and organizational factors that can influence whether a state bureaucracy can successfully implement a nuclear weapons acquisition plan.

The conclusions offer suggestions for improved assessments of nuclear latency in the future. Instead of chasing the quixotic goal of a single measure of nuclear latency, scholars should seek to understand how political factors can influence technological developments in this arena and how reaching various thresholds in nuclear power technology can affect the politics of proliferation decisions. Unfortunately, the field's long-standing intellectual tradition of dividing the proliferation puzzle into "supply-side" and "demand-side" factors has reduced attention on the crucial and complex relationship between the supply of nuclear technology and the demand for nuclear weapons. In the conclusion, I therefore outline how one might better conceptualize and study the nature of nuclear latency and its relationship to the acquisition of nuclear weapons. In addition to sketching out an interdisciplinary research agenda, the chapter ends with a discussion of how an improved understanding of nuclear latency could influence policy debates regarding nuclear disarmament, managing the fuel cycle, and the future of the NPT.

(MIS)QUOTING MOHAMED

In his September 2004 address to the IAEA General Conference, Director General Mohamed ElBaradei stated:

> Some estimates indicate that 40 countries or more now have the know-how to produce nuclear weapons, which means that if they have the required fissile material—high enriched uranium or plutonium—we are relying primarily on the continued good intentions of these countries, intentions which are in turn based on their sense of security or insecurity, and could therefore be subject to rapid change. Clearly, the margin of security this affords is thin, and worrisome.[1]

The subtlety of ElBaradei's argument and conditional nature of this prediction—"*if* they have the required fissile material"—were, however, often ignored. A National Defense University study, for example, cited ElBaradei when it claimed that there now exists "a high degree of *nuclear latency* that challenges traditional thinking about nuclear threats": "whereas 30 or 40 years ago, only a handful of countries were assumed to know how to acquire nuclear weapons, as many as 35 or 40 nations currently are believed to be in the know."[2] The Austrian government switched "know-how" into "technical capability" in its 2007 NPT Preparatory Committee statement: "Approximately 40 countries are said to have the technical capability to produce nuclear weapons."[3] In some cases, the problem went beyond imprecise language to clearly misleading claims, such as the 2005 pronouncement by Greenpeace: "Through the IAEA's worldwide support of nuclear power, 35–40 countries today have the capability of building atomic weapons in several months, as Dr. ElBaradei recently admitted."[4]

A second commonly cited statement is ElBaradei's October 2006 comment about the potential for many "virtual nuclear weapons States" around the globe:

> Verifying enrichment facilities or reprocessing facilities is quite difficult and the so-called conversion time is very short. So we are dealing with what I call

> "virtual nuclear weapon States." One of the issues I have been talking about for a number of years is the need to develop a new international or multinational approach to the fuel cycle so as to avoid ending up with not just nine nuclear weapon States but another 20 or 30 States which have the capacity to develop nuclear weapons in a very short span of time.[5]

Again, the conditional nature of this prediction—referring to a future world if more states develop independent enrichment or reprocessing technology—was widely ignored. For example, Zia Mian claimed that "Mohamed ElBaradei of the [IAEA] warned that there are another 20 or 30 'virtual nuclear weapons states' that have the capacity to develop nuclear weapons in a very short time span."[6] John Feffer, Marcus Raskin, and Kevin Martin similarly claimed that there are "20–30 virtual nuclear weapons states, which Mohamed ElBaradei of the . . . IAEA . . . warns have the capacity to develop nuclear weapons in a very short time span."[7]

Such statements by journalists, diplomats, and scholars clearly exaggerate the number of states that could build nuclear weapons in a short time period. But they also point to a deeper conceptual confusion about the nature of nuclear latency. How could one measure it? What are the relationships among acquiring research or power reactors, constructing uranium enrichment or reprocessing facilities, developing fissile material, and acquiring nuclear weapons? A logical place to start would be the political science literature on nuclear latency. Unfortunately, such literature on the subject has not been very helpful, in large part because it has failed to focus on the nuclear fuel cycle.

THE POVERTY OF POLITICAL SCIENCE ON NUCLEAR LATENCY

This failure is due in part to the tendency in social science scholarship of the past decade to focus on the "demand side" of the nuclear proliferation puzzle. This emphasis on the motives of governments to develop or refrain from developing nuclear weapons was understandable. Much of the earlier political science literature had focused on the effects of arms control treaties, export controls, and other technical constraints on the supply of nuclear materials and technology, and an increase in attention to why some governments wanted nuclear weapons, and why some governments did not, was clearly needed.[8] Moreover, the emergence of nuclear "proliferation rings," such as the A. Q. Khan network and other technology smuggling efforts, encouraged fears that it would be increasingly difficult to prevent weapons proliferation through "supply-side" constraints.[9] Finally, as will be demonstrated shortly, the quantitative literature on the "correlates of nuclear proliferation" began to present surprising evidence on the rapid growth in the number of states that were "nuclear weapons capable."

Such considerations have led some prominent political science scholars to be highly skeptical of efforts to control the supply of nuclear technology for the purposes of nonproliferation. For example, in his innovative book *The Psychology of Nuclear Proliferation*, Jacques Hymans argues that "given the widespread diffusion of nuclear capacities, supply-side control measures against potential proliferant states are clearly of declining utility":

> A stricter regime will likely do nothing to change proliferation intentions. It is highly unlikely that more stringent controls will dissuade oppositional nationalist leaders from seeking the bomb and in today's freewheeling global market they probably will be able to obtain the materials they need to build it, albeit perhaps more slowly and with difficulty. More problematically, it is highly unlikely that more stringent controls will dissuade sportsmanlike nationalist leaders from resisting the nonproliferation regime. Indeed, the harsher the regime becomes, the more likely that both types of nationalists will resent and resist it . . . In short, the construction of ever-higher supply-side hurdles to civilian nuclear development, far from "strengthening" the non-proliferation regime, is in fact likely to leave the regime even weaker than it is today.[10]

Hymans admittedly does not want "to abandon the NPT regime," although he does "second-guess the continual urge to 'strengthen' it with ever-heavier supply-side controls."[11] Yet Hymans is by no means alone among the political scientists who have studied nuclear proliferation in criticizing continuing efforts to control nuclear technology through the NPT. Dong-Joon Jo and Erik Gartzke also find a strong positive correlation between a state getting "latent nuclear weapons production capabilities" and the initiation of a nuclear weapons program, and they maintain that "the inhibiting effect of the NPT is overcome by the stronger technological diffusion effect," concluding that "enthusiasm for the NPT among proliferation opponents thus appears to be misplaced."[12] Harsh Pant has been even more dismissive of the NPT, claiming that the treaty "was never sustainable and has had little, if any, effect on the pace of nuclear proliferation."[13]

Such conclusions regarding the NPT are not warranted based on historical evidence. The underlying assumption, that more and more states have become "nuclear weapons capable," depends crucially on how one defines and measures "nuclear latency." An important weakness, however, in the ways in which political scientists have measured nuclear latency becomes clear only after one delves deeply into the methodology used in their studies.

What does it mean for a state to be "capable" of producing nuclear weapons? Hymans's assessment of what he calls "latent nuclear capabilities" is based on the methodology and data set used in Stephen Meyer's pioneering 1984 book *The Dynamics of Nuclear Proliferation* and Richard Stoll's update of the Meyer data through 1992. Meyer's study carefully measured a set of ten technical and economic indicators—national mining activity, indigenous uranium deposits, metallurgists, steel production, construction work force, chemical engineers, nitric acid production, electrical production capacity, nuclear engineers, physicists, chemists, and explosive and electronics specialists—to produce what he called "a list of nations with latent capabilities to manufacture nuclear weapons."[14] Not being able to measure directly whether the quantity or quality of a state's nuclear engineers and its explosive and electronic specialists were sufficient to build a nuclear weapon, Meyer used two proxy indicators: whether the state had been operating a research reactor for three years (the proxy for nuclear engineering expertise) and whether the state manufactured automobiles or assembled automobiles and manufactured radios and television sets (the proxy for explosive and electronics specialists). Based on this particular set of indicators, Meyer found that thirty-four states held the latent capability to build nuclear weapons in 1982.[15] Stoll updated the Meyer data set, but with a hidden yet significant change in coding rules, in the mid-1990s (see Figure 5.1): While Meyer measured indigenous uranium sources, Stoll assumed that all states had access to nuclear materials, arguing that they were now freely available in the global marketplace. Stoll thus simply assumed away the crucial issue of whether a state had access to uranium that, once enriched, could be used in a nuclear weapons program. Based on the resulting data set, Stoll argued that forty-eight states had a latent nuclear weapons capability in 1992, noting that:

> A country is said to have a *latent capacity* when it has sufficient technical, industrial, material, and financial resources to support a wholly indigenous weapons program. Even though a state may have a latent capacity, it must still make an explicit decision to develop the particular facilities necessary to create weapons. However, once a state *has* a latent capacity, it is very difficult—perhaps impossible—to deny it nuclear weapons, since it is in essence self-sufficient.[16]

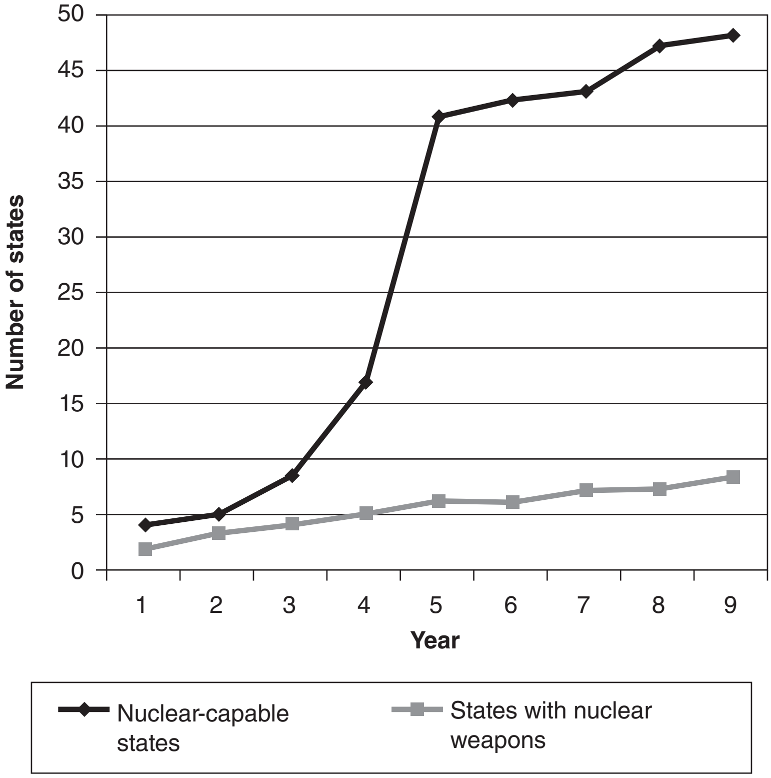

Figure 5.1. Stoll's nuclear latency estimate.
SOURCE: Data from Richard Stoll, "Latency Capacity Proliferation Model"; available at http://es.rice.edu/projects/Poli378/Nuclear/Proliferation/

Hymans accepted the logic of that argument and claims that the Stoll data demonstrate that there was a "yawning gap between technical potential and military reality" in terms of the number of states that have capability to produce nuclear weapons compared to those that have actually done so.[17] (I depict the Stoll data in Figure 5.1.)

A state can not make a nuclear weapon, however, unless it has HEU or plutonium from a large reactor, and Stoll's hidden assumption that any state could acquire uranium on the open market, coupled with his use of research reactor experience as the measure of required nuclear engineering expertise, essentially assumed away those two technical constraints. Moreover, looking at his data set reveals that even though Stoll argued that each of his ten criteria were "necessary conditions for the production of nuclear weapons," North Korea, which the IAEA discovered had taken spent fuel rods containing plutonium from the Yongbyon reactor in 1989, 1990, and 1991,[18] was not considered capable of building a nuclear weapon according to Stoll's model in 1992. North Korea lacked the necessary nitric acid production capability, chemical engineers, and electronic/explosives specialists (as measured by domestic automobile and radio/television industry). This observation obviously raises questions about whether these particular measures of nuclear latency really are "necessary conditions" for a state to develop nuclear weapons.

Jo and Gartzke's 2007 *Journal of Conflict Resolution* study "The Determinants of Nuclear Weapons Proliferation" improves on the Stoll coding scheme by dropping three of the Stoll and Meyer indicators (construction workforce, steel production, and previous national mining activity) on the grounds that they are "too easily available to be thresholds" and modifying the coding for necessary "uranium deposits" (which, as we have seen, were assumed to be

Table 5.1. Comparison of Meyer/Stoll and Gartzke and Jo nuclear capability indicators.

	Definition of indicator	
Indicator	*Meyer/Stoll*	*Gartzke and Jo*
Mining activity	Some fraction of labor force in mining activity	————
Uranium deposits	Known uranium deposits (Meyer) Assumed market access (Stoll)	Known uranium deposits or produced uranium already
Metallurgists	Production of crude steel	Production of crude steel or aluminum
Steel	Production of crude steel	————
Construction work force	Production of steel and cement	————
Chemical engineers	Production of nitric acid or sulfuric acid	Production of nitric acid or sulfuric acid
Nitric acid production capacity	Nitric acid production or sulfuric acid production and nonorganic nitrogenous fertilizer production	Nitric acid production or sulfuric acid production and nonorganic nitrogenous fertilizer production
Electricity production capacity	Installed electrical capacity of 200MWe	Installed capacity of 200MWe or produces equivalent of 50,000 metric tons of oil
Nuclear engineers/ physicists/chemists	Three research-reactor years	Three research-reactor years
Electronics/explosives specialists	Manufacture of motor vehicles or assembly of motor vehicles and manufacture of radios or TVs	Manufacture or assembly of motor vehicles and manufacture of radios or TVs

available for all states by Stoll) to include either a state with uranium deposits on its territory or one that has acquired "produced uranium" for a research or power reactor.[19] (See Table 5.1 for a comparison of the various coding schemes.)

Yet, although Jo and Gartzke correctly note that "states that lack the basic material capabilities will be excluded from the group of potential proliferators," their model actually does not treat nuclear materials (enriched uranium or plutonium) as a necessary, but not sufficient, condition for building nuclear weapons.[20] Instead, their model implicitly assumes that "where there is a will, there is a way" and that a latent nuclear weapons state, or even a state that has already made nuclear weapons, may not actually have the necessary materials. That the Jo and Gartzke model does not therefore adequately capture the necessary conditions for nuclear weapons development can be best seen in the representation of their data set for 2001 presented as a map in Figure 5.2.[21] The Jo and Gartzke data set continues to show that North Korea did not have a full latent capability to develop nuclear weapons in 2001 (it still lacked sufficient chemical engineers, nitric acid production capability, and explosives specialists), even though the North Koreans were a major exporter of long-range missiles at the time and were known to have separated plutonium from the fuel rods of the Yongbyon reactor.[22] We now also know that North Korea tested its first nuclear weapon in 2006. The Jo and Gartzke coding rules also lead to the odd conclusion that South Africa, which built six nuclear weapons in the 1980s, dismantled the weapons in the 1990s but still maintained from 450 to 600 kg of HEU under IAEA safeguard inspections in 2002, nevertheless lacked the full capability to build nuclear weapons.[23] (South Africa lacked sufficient chemical engineers and nitric acid production capacity, according to their data.)

By not focusing attention on enriched uranium and plutonium, the weak proxy measures of nuclear latency used in this work clearly lead to bizarre results. Trinidad and Tobago (which "only" lacks uranium deposits, "produced uranium," and any research reactor experience) is assessed to have a higher degree of nuclear weapons latency in 2001 than is North Korea, only five years away from detonating its first nuclear weapon. In Africa, Egypt, which had only two research reactors in 2001, is assessed to have a higher degree of nuclear weapons latency than is South Africa.

In addition, Jo and Gartzke usefully try to assess the nuclear *diffusion effect* in an attempt to understand whether "knowledge of how to construct nuclear weapons has spread with the passage of time" and how much this has

Figure 5.2. Nuclear latency according to Jo and Gartzke.
SOURCE: Data from Dong-Joon Jo and Erik Gartzke, "Dataset for 'Determinants of Nuclear Proliferation: A Quantitative Model,'" *Journal of Conflict Resolution* 51, no. 1 (2007), available at: http://jcr.sagepub.com/cgi/content/full/51/1/167/DC1

influenced proliferation.[24] Their measure of "nuclear diffusion," however, is devoid of substantive content. Because Jo and Gartzke had no direct measure of the spread of nuclear knowledge over time, they simply assumed that "diffusion equals the log transformation of the number of years since 1938."[25] This variable may measure some temporal factor that affects changes in proliferation behavior over time but does not, contrary to their claim, "suggest that the NPT may actually contribute to the quickening pace of nuclear diffusion."[26]

In conclusion, these problems point to serious weaknesses in the political science literature analyzing nuclear latency and the effects of the NPT. All too often this literature measures "proxy variables" that are easily available, rather than collecting the data that reflect the variables of real interest. All too often there are hidden, but crucial, assumptions that have a strong impact on the findings in ways that are not acknowledged. Most importantly, the political science literature, like the misinterpretations of ElBaradei's statements cited earlier, often conflates two analytically different phenomena under the same labels of "nuclear weapons capability" or "nuclear latency"—first, what should properly be called "nuclear self-sufficiency" (a measure of how independent a potential long-term nuclear weapons program could be); and, second, "nuclear latency" (a measure of how quickly a state could develop a nuclear weapon if it chose to do so from its current state of technological development).[27] The former may have value in estimating whether a state could develop nuclear weapons *eventually*, over an extended period of time, even if it received no technical assistance or nuclear materials from other states. This is a phenomenon, however, that has never happened in world history, as all nuclear weapons states have received some degree of assistance from others, as Itty Abraham has compellingly demonstrated: Even the first nuclear weapons states, the United States and the Soviet Union, were not self-sufficient, having received assistance from German scientists, scientists from closely allied nations, and spies from other states' programs.[28]

In short, by focusing our attention away from the acquisition of the fissile materials needed to make a nuclear weapon, the political science literature has led to an exaggerated estimate of how many states currently have the technical capability to build nuclear weapons. The criticisms of the NPT regime cited above—that it has been ineffective or even may have led to the widespread diffusion of latent nuclear weapons capability—are therefore unwarranted. The NPT regime clearly has flaws, and we know of many cases of states that have violated their commitments, but the NPT has not (at least not yet) led to a world in which there are dozens of non–nuclear weapons states that could easily become nuclear weapons states in a short period of time.

TECHNOLOGY, THE FUEL CYCLE, AND NUCLEAR WEAPONS

The biggest problem in these political science studies was their failure to focus on the fuel cycle technology necessary to produce the fissile materials needed for a weapon. Without a large nuclear reactor to produce plutonium (and a reprocessing facility) or the capability to produce enriched uranium, no state could build its own nuclear weapon. Does a state have nuclear power reactors or other reactors that produce plutonium? How large are its research reactors, and do they run on low enriched uranium (LEU) or HEU? Does it have the technological capability to produce, separate, or reprocess plutonium? Does the state have an enrichment facility to produce HEU? How long would it take to build such facilities and then to build a nuclear bomb with the materials? Such questions should be at the core of any assessment of a state's latent nuclear weapons capability.

Fortunately, there is a strong technical literature on nuclear power and proliferation that addresses such questions. Yet even the most thorough of these studies ignore important political factors that strongly influence proliferation decisions and their implementation. I will review three important studies of nuclear technology to illustrate the point.

The pioneering study on this subject was the 1977 book *Swords from Plowshares*, produced by an interdisciplinary team of scholars led by Albert Wohlstetter.[29] Wohlstetter and his colleagues divided non–nuclear weapons states into three categories—states with advanced infrastructure and fissile material, states with a research or power reactor, and states with no nuclear experience at all. In the first category were the nine states that were estimated to have "full access to the fissile material required to make a weapon" in 1977: Japan, West Germany, South Africa, Belgium, Taiwan, Italy, the Netherlands, Canada, and Sweden. The study argued that each of these states could take the following four remaining steps to produce a nuclear weapon within one year, assuming the steps were undertaken in parallel: converting the fissile material in their possession into metallic form, designing a weapon, fabricating the weapon and its components, and preparing for and conducting a nuclear test.[30] In the second category, *Swords from Plowshares* listed fifteen states that had a reactor in 1977 but no access to fissile material outside of the spent fuel rods: Israel, Argentina, Switzerland, Egypt, Spain, South Korea, Indonesia, East Germany, Czechoslovakia, Australia, Pakistan, Iran, Norway, Brazil, and Mexico. The study assumed that the most practical pathway for such states to get a nuclear weapon would be to construct a reprocessing plant, which the study estimated would take four years. It assumed that the four final weaponization steps listed above could be done in parallel to the reprocessing efforts (though the authors never explained how a state could produce plutonium metal before the reprocessing plant was completed and in operation) and thus estimated that any of these states could make a nuclear weapon in four years.[31] Finally, states in the third category were estimated to need at least six years to build a nuclear reactor and simple reprocessing facility "from scratch." (See Table 5.2 for the countries in each category.) Wohlstetter and his team acknowledged that these timelines were "engineering estimates based on American experience" and should therefore only be considered "rough approximations."[32]

Swords from Plowshares was an influential and prescient study. Wohlstetter and his colleagues identified the danger of what they called "nearing the bomb without breaking promises not to make it" under the NPT.[33] They discussed the need for a more extensive system of IAEA inspections of non–nuclear weapons states' facilities and produced one of the first analyses of the pros and cons of building multinational nuclear fuel facilities. With the passage

Table 5.2. Wohlstetter et al.'s nuclear capability timeframes.

	Capability level (NNWS only)		
	Advanced nuclear infrastructure plus "full access to fissile material needed for bomb"	Research or power reactor; no fissile material except in reactors and spent fuel rods	No nuclear infrastructure
Countries qualifying (as of 1977)	Japan, West Germany, South Africa, Belgium, Taiwan, Italy, Netherlands, Canada, Sweden (9)	Israel, Argentina, Switzerland, Egypt, Spain, Republic of Korea, Indonesia, East Germany, Czechoslavakia, Australia, Pakistan, Iran, Norway, Brazil, Mexico (15)	All other states
(Assumed) obstacles remaining	(a) Convert fissile material to metal; (b) design weapon; (c) fabricate weapon; (d) test	(a) through (d) plus concurrent construction of reprocessing plant	Build reactor and reprocessing plant
Estimated time to first bomb	1 year	4 years	6+ years

Source: Data from Albert Wohlstetter, Thomas A. Brown, Gregory Jones, David C. McGarvey, Henry Rowen, Vince Taylor, and Roberta Wohlstetter, *Swords from Plowshares: The Military Potential of Civilian Nuclear Energy* (Chicago: University of Chicago Press, 1977).

of time, however, one can also see some obvious weaknesses in this pioneering work. First, by basing the estimates for nuclear latency time lines on the *U.S. experience*, the study implicitly assumes that all proliferators are likely or able to follow the same technological pathways, with the same degree of bureaucratic and organizational competence and the same degree of wartime and Cold War urgency. Wohlstetter and his colleagues also assumed that once a government made a decision to develop nuclear weapons, there would be a high degree of political consensus behind it and the weapons program would progress without significant internal or external constraints. The estimate on the "starting from scratch" scenario seems particularly low and appears to contain a hidden assumption that the world market would encourage such growth in reprocessing facilities and that the United States and the global nonproliferation regime would not add additional political hurdles to constrain that growth.

To be fair, the alarm bell sounded by the Wohlstetter study was a kind of self-denying prophecy because it was a major contributor to the development of future nonproliferation innovations, at least in the United States.[34] *Swords* *from Plowshares* also contained a useful discussion of the need for more rigorous agreements among governments that exported nuclear technology on what could be sold and what could not be sold, even to NPT member states. Still, this important 1977 technical study could have been supplemented at the time (and certainly needs to be supplemented now) with both analyses of alternative weapons development pathways and historical data on actual political decision making and bureaucratic implementation in different states' programs that could provide more accurate evidence to support estimates of future latency timelines.

The second study focused on technology contributing to nuclear latency is the 2006 *Science and Global Security* article by Robert Harney and his colleagues entitled "Anatomy of a Project to Produce a First Nuclear Weapon."[35] The authors identify and provide a complex timeline of the 196 necessary tasks required to produce a uranium-based nuclear weapon by a state that has produced or acquired 120 metric tons of yellowcake. The tasks include production of enrichment-plant feed material (UF6), uranium enrichment (with timelines for different enrichment methods), production of HEU metal, and finally the design and construction of actual nuclear weapons.[36] Using measures of time, labor, energy, and necessary money required to complete these tasks under both normal and expedited ("crash") conditions, the authors provide an estimate of the earliest possible completion time: under normal conditions, approximately 338 weeks (six and a half years) would be needed to produce six weapons, and under crash conditions 260 weeks, or just under five years, would be required.[37] Harney and his coauthors also provide an estimate of an Iranian withdrawal from the NPT breakout scenario: According to their model, it would still take 216 weeks (about four years) for a state that has a prototypic uranium enrichment plant already in place to produce its first nuclear weapon.[38]

The Harney and colleagues study usefully highlights the complexity and time needed to produce uranium metal from highly enriched uranium and for subsequent steps in the weaponization process. By developing estimates of both crash programs and noncrash programs, the study brings one political variable into its analysis. But there are nonetheless limits to its utility as a guide to understanding nuclear latency in future proliferation scenarios. First, the authors, like those contributing to the Wohlstetter study, base their estimates on the U.S. experience with nuclear materials and weapons production.[39] This could bias the results in both directions, though it is difficult to know which bias would be stronger. On the one hand, the study assumes a high degree of organizational competence on the part of future proliferators, which would likely make the Harney estimates lower than is likely to occur in most new proliferant states in developing world. On the other hand, the study also assumes that future proliferators would copy the later U.S. Cold War penchant for careful testing, stringent safety, and high reliability, tasks that take time and would make the estimates derived from the model much too long. (For example, the study estimates it would take twenty-four weeks to verify gun velocity, twenty-four weeks to build a delivery vehicle compatibility mock-up, and forty weeks to finalize the weapons design.[40]) From a U.S. weapons designer's view, such assumptions may reflect normal peacetime procedures; from a proliferation prevention perspective, they may constitute a wishful thinking, best-case analysis. For example, if a new proliferant government decides to use a simple uranium gun-type device or has access to the more advanced nuclear bomb designs that were peddled by the A. Q. Khan network, these time-consuming activities could be greatly reduced. The Harney study also assumes that a proliferant government has not developed covert facilities to jumpstart the weaponization process, having most essential tasks completed before the HEU is produced.

The third, and most historically grounded, technical study on nuclear latency is a detailed 2005 report from the Pacific Northwest National Laboratory (PNNL): *Nuclear Proliferation Technology Trends Analysis*.[41] The PNNL study does not base its estimates on the U.S. experience with different nuclear-related technologies but rather gathers and presents the available data on the experience and time lags seen in the history of many different states' uranium enrichment and plutonium production and reprocessing programs. The study is the most detailed analysis, at least in the unclassified literature, of the history of successful efforts either to enrich uranium or reprocess plutonium. The PNNL authors wisely do not "sample on the dependent variable" and therefore also analyze failed or abandoned programs to enrich uranium or reprocess plutonium. I reproduce the concluding estimates about nuclear materials production time lines from the PNNL study in Table 5.3.

This PNNL study is valuable, but its claims to be able to use history to provide accurate estimates about technical time constraints that continue to apply today are problematic. The study correctly notes that "the time required for success varies widely and is strongly dependent on either help from nations that have already developed the technology or the nuclear and industrial maturity of the nation."[42] But the authors do not analyze the evolution of

Table 5.3. PNNL nuclear capability timeframes.

Technology	*Number of countries interested in technology*	*Number of countries with successful production programs*[1]	*Average time to pilot plant*[2]	*Average time to production*[3]
Gaseous diffusion enrichment	6	5	———	6 years
Centrifuge enrichment	18	7	8 years	14 years
Electromagnetic isotope separation	11	1	2 years	3 years
Chemical isotope separation	3	———	6 years	11 years
Aerodynamic isotope separation	3	1	7 years	18 years
Laser enrichment	14	———	———	———
Graphite-moderated production reactors	6	6	1 year	2–11 years[4]
Heavy-water-moderated reactors	12	5	1 year	2–6 years
Research reactors	14	3	———	4–5 years
Reprocessing	19	13	6 years	10 years

Source: M. D. Zentner, G. L. Coles, and R. J. Talbott, *Nuclear Proliferation Technology Trends Analysis*, Pacific Northwest National Laboratory, September 2005; available at www.pnl.gov/main/publications/external/technical_reports/PNNL-14480.pdf

[1] More than gram quantities of material produced [note in original].

[2] Technological capability demonstrated [note in original].

[3] Significant quantities of material produced [note in original].

[4] Note that "average" times given in this cell and the two cells immediately below it are in fact ranges, not averages.

international export controls on nuclear technology, which have strengthened over time and thus influence late developers more than early developers of some nuclear materials production technologies. The authors maintain that "based on an evaluation of historical trends in nuclear technology development, conclusions can be reached concerning: 1) the length of time it takes to acquire a technology; 2) the length of time it takes for production of special nuclear material to begin; and 3) the type of approaches taken for acquiring the technology."[43] History surely can provide an answer to point three, but the other two questions are historically contingent on the characteristics of the states involved and can change depending on the spread of other related technologies, organizational learning, illicit networks of suppliers, and shifts in foreign government assistance. The authors' calculations of "average" times to pilot plants and "average" times to production success are interesting but have a peculiar ahistorical character to them; and, even if the full ranges of historical time lines were presented, using the lowest number as a "worst-case estimate" would be problematic because these time lines include advanced industrial states as well as less-developed nations. In short, future scholars should be more cautious than were the PNNL authors when they concluded that "the timeframes identified above can be considered representative of current development efforts."[44]

TOWARD A POLITICAL THEORY OF NUCLEAR LATENCY AND PROLIFERATION

These considerations lead me to conclude that any general measure of "nuclear latency" is likely to be a chimera. Nuclear latency is not like human pregnancy, in which all women have virtually the same nine month gestation period. Different non–nuclear weapons states, even those starting from the same technological threshold, are likely to take different lengths of time to move to possession of a single nuclear weapon or a usable arsenal.

Where should the political science and technical community go from here to improve our understanding of nuclear latency and the risks of nuclear proliferation in the future? And how would such research help us understand how the NPT works to constrain proliferation? This conclusion outlines a multidisciplinary research agenda and suggests some principles that should guide future research to avoid some of the weaknesses of past efforts in this area. I then conclude with some policy-relevant observations about how new agreements regarding the fuel cycle facilities and produced fuels could strengthen the NPT regime.

First, we need more research on the domestic characteristics of the regimes that have been successful and of those that have been less so in their attempts to develop uranium enrichment and plutonium reprocessing capabilities. Such analysis would have to take into account the degree to which the "failures" or longer time lines for successful states were due to internal characteristics or external constraints. The simple division between democracies and nondemocracies may be less helpful in this regard than a focus on the relationship among the political leadership and the scientific community and military. Jacques Hymans, for example, usefully theorizes that "neopatrimonial" or "sultanistic" regimes—governments characterized by extreme personalized rule, use of state resources to buy off clients, and an absence of checks and balances—will take longer to develop advanced levels of nuclear technology and will fail more often in attempts to move from one technological threshold to the next.[45] Hymans argues that North Korea fits this model and compares it to Romania, where an unsuccessful program was run by Elena Ceauşescu, the president's wife, who hired scientists based primarily on whether they would promote her candidacy for the Nobel Prize in chemistry; and Libya, which was described by the 2005 WMD Commission as "an inept bungler, the court jester among the band of nations seeking biological and nuclear capabilities."[46] This is a promising approach, yet it is important to note that North Korea, unlike Romania and Libya, was able to produce fissile materials despite international sanctions. North Korea tested a nuclear device in 2006, though this device was not as effective as was apparently expected, and another in 2009, widely considered to have been successful.[47] In addition, it is worth noting that Saddam Hussein's regime in Iraq was characterized by massive corruption, a culture of fear that led to exaggeration of progress by laboratory officials and military commanders alike, and a decision-making style that, according to his senior colleagues, "verged on the mystical."[48] Despite such pathological decision making and leadership, however, the Iraqi covert program was discovered after the 1991 Gulf War to be much closer to producing a nuclear weapon than the CIA had estimated.[49]

Another potential political constraint on nuclear weapons programs can be the rivalries for power between different leaders in potential proliferators. In Egypt in the 1960s, for example, Gamal Abdel Nasser started a nuclear weapons program but did not give it high priority or a large budget, in part because the head of the nuclear program was a strong ally of Nasser's chief rival, Abdel Hakim Amer. As one former military officer later explained: "We didn't want to create heroes in the system that a nuclear bomb would create."[50]

In short, more research on how regime characteristics influence the ability to develop both fissile materials and nuclear weapons should be pursued. We have a strong literature on how regime type can influence decisions about *whether* to seek nuclear weapons. But we lack broader studies of how regime characteristics influence the ability *to implement* decisions to acquire sensitive nuclear technology or use such technology to move closer toward developing a nuclear arsenal. Such research should avoid, however, the common assumption that governments that seek nuclear weapons options have already decided to get the bomb. As Itty Abraham argues, the proliferation/nonproliferation lens through which scholars commonly study nuclear history can blind us to the diversity of motivations of different bureaucratic actors within states and even the mixed motives of individual leaders. The nonproliferation literature commonly refers to "nuclear ambiguity": the lack of knowledge about whether a foreign government is pursuing nuclear weapons or only nuclear energy. In some cases, however, a government would be better described as experiencing "nuclear ambivalence" because its leadership is undecided or deeply conflicted about different options for future nuclear development.[51]

A second line of research could focus on the time period between when states acquired weapons-usable fissile materials and when they tested a weapon or had a suspected nuclear weapons arsenal. Such research would be difficult, of course, because of the lack of firm information on the dates of nuclear program initiation and successful acquisition of a nuclear weapon in many historical cases.[52] Even if accurate dates were available, however, scholars should be careful not to assume that each of these different governments was seeking nuclear weapons with the same degree of urgency or unity. Even among the states that did eventually develop nuclear weapons, one finds some governments initiating nuclear weapons programs on a crash basis in wartime or crisis conditions, others slowly developing a hedge for an uncertain future in peacetime, and others initiating a nuclear power program or peaceful nuclear explosive program with only minimal interest in nuclear weapons applications.

This line of research could also usefully focus on the political and technical factors that influence the size and characteristics of the nuclear arsenals sought by new nuclear proliferants. Any analysis of nuclear latency timelines should therefore be mindful of the assumptions used not only about the starting point (the capacity of an individual enrichment facility or reprocessing facility) but also about the end point sought by the state (a single weapon, an arsenal, a simple nuclear device, a miniaturized warhead?). The characteristics of the arsenal sought by a government have a major impact on the financial costs, the technical hurdles, and the time involved in a nuclear program. For example, although outside observers often claim that it would take Japan six months to a year to develop nuclear weapons if it chose to do so,[53] an internal Japanese government study after the North Korean test reportedly calculated that it would take Japan three to five years to construct a breeder reactor, expand its reprocessing facility, and build a prototype of a miniaturized warhead capable of fitting onto a missile to counter the DPRK threat.[54] Unfortunately, we know little about what would-be proliferators think about what kinds and levels of nuclear weapons might be needed to meet their security requirements.

Third, it would be useful to have more technical and political science research on the effectiveness of past efforts to control the spread of uranium enrichment and plutonium reprocessing. Recent studies by Matthew Fuhrmann and Matthew Kroenig have contributed significantly to the field by examining the political and economic causes and the security consequences of international exports of sensitive nuclear facilities, nuclear cooperation agreements, and sales of nuclear reactors.[55] This line of research could be extended to examine the effectiveness over time, or lack thereof, of strengthened export controls, the creation of the Nuclear Suppliers Group, and rise and fall of the A. Q. Khan network.

Finally, there should be more integrated studies of supply *and* demand for nuclear weapons. Instead of thinking about these two "sides" of nuclear proliferation as separate issues, we need to recognize, and therefore study, the potential for complex connections between supply and demand. Three such interactions are obvious. First, how hard a government works on a nuclear weapons program—the resources it commits to the program and whether it is engaged in a crash effort or normal construction effort—is likely to be affected by the severity of its demand for a weapon. Second, a high degree of nuclear capability or latency could influence demand by enabling actors favoring a nuclear weapon to argue that acquiring a weapon is easier than would otherwise be the case. Third, a high degree of latency could make it easier for a pronuclear weapons party or individual leaders to implement a decision to acquire nuclear weapons if they are in power for only a brief period of time.

NUCLEAR POWER WITHOUT NUCLEAR PROLIFERATION?

Concerns about climate change and growing energy demand have sparked a global resurgence of interest in civilian nuclear power generation. The potential increase in nuclear power reactors in experienced states and the spread of nuclear power to new states will inevitably boost the demand for enriched uranium to fuel such reactors and increase interest in reprocessing to recycle plutonium from the back end of the fuel cycle. Will it be possible to have the expansion of nuclear power without enhancing the risk of global nuclear proliferation?

A final research task would be to understand more about how the growth of civilian nuclear power bureaucracies in different states influenced their decisions to seek or renounce nuclear weapons. Indeed, how best to ensure that civilian nuclear power bureaucracies maintain a strong interest in opposing nuclear weapons proliferation may be the proverbial "$64,000 question" for the future of nuclear nonproliferation. (It will be closer to a $64 billion question in reality.) On the one hand, leaders of successful nuclear power enterprises would likely want to maintain strong ties to the global financial markets, nuclear power industry, and regulatory agencies and hence seek cooperation with the nuclear nonproliferation regime. On the other hand, leaders of less successful or struggling nuclear power enterprises might be more likely to support nuclear weapons development programs as tools to justify their existence and budgets within their state. Etel Solingen notes how crucial the former factor has been in promoting nuclear weapons restraint in East Asia; Itty Abraham has, in contrast, demonstrated that the weak record in producing nuclear power encouraged India's "strategic enclave" in the nuclear laboratories to lobby New Delhi to acquire nuclear weapons.[56]

The degree to which the expansion and spread of nuclear power will increase individual countries' latent nuclear weapons capability will be largely determined, however, by who manages and controls uranium enrichment facilities and plutonium separation and reprocessing facilities. Fortunately, there are many potential reforms of the international regime, including the NPT, that could reduce states' incentives and capabilities to acquire nuclear weapons even in a world of expanded nuclear power. First, as demonstrated in ElBaradei's statements discussed earlier, there is significant interest in the creation of international nuclear fuel banks, multinational fuel production facilities, and spent fuel take-back arrangements that would permit expansion of nuclear power without expansion of national fuel production facilities. Second, the Nuclear Suppliers Group or even a future NPT Review Conference could discourage states from exercising their Article X right to withdrawal from the NPT by making future sales of nuclear fuels and sensitive technology subject to a "Return to Sender" agreement. U.N. Security Council Resolution 1887 explicitly encourages such a "Return to Sender" policy by requesting that nuclear supplier states:

> require as a condition of nuclear exports that the recipient State agree that, in the event that it should terminate, withdraw from, or be found by the IAEA Board of Governors to be in non-compliance with its IAEA safeguards agreement, the supplier state would have a right to require the return of nuclear material and equipment [. . .] as well as any special nuclear material produced through the use of such material or equipment.[57]

Unfortunately, many non–nuclear weapons states fear that efforts to enhance international controls over the nuclear fuel cycle cut against their "inalienable right" as specified in Article IV to enjoy the benefits of nuclear energy. These concerns should, however, be balanced by the hope that both nuclear disarmament and nonproliferation will be enhanced by strong international control of the fuel cycle. George Perkovich and James Acton have compellingly argued that weapons states are less likely to agree to complete nuclear disarmament or go to extremely low numbers in the future if many other states have their own uranium enrichment or reprocessing facilities and could therefore develop nuclear weapons openly and more rapidly in an NPT withdrawal scenario or covertly in peacetime.[58] There is, therefore, an important logical connection between future controls over the nuclear fuel cycle and nuclear disarmament. The governments of non–nuclear-weapons states should recognize that entering into negotiations about international control of the nuclear fuel cycle is part of *their* Article VI commitment "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race."[59] If nuclear disarmament is ever to occur, it is obvious that all the nuclear weapons states will need to negotiate to reduce and eliminate their arsenals in a mutual and verifiable manner. It is less obvious, but no less true, that the prospects for eventual nuclear disarmament will be linked to the success or failure of the global effort to negotiate serious constraints on the global spread of enrichment and reprocessing facilities.