Nuclear Energy in the Transition to a Nuclear-Weapon-Free World

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ABSTRACT. The paper examines how civilian nuclear energy can best be managed and safeguarded in the transition to a nuclear-weapon-free world. Clearly, whatever the specific fuel-cycle configuration, possession of civilian nuclear power would shorten the time required for a country to break out of a disarmament agreement and produce some or many nuclear weapons. By the same token, such possession also would allow a more rapid deployment or redeployment of nuclear weapons by a country wishing to respond to the breakout country. The existence of a civilian nuclear program would probably also make more possible, though still difficult, a clandestine program to produce nuclear explosive material, which if successful could shorten the time for the international community to react against a country breakout. The paper sets out preliminary estimates of the times required for a state to acquire, overtly and clandestinely, a few to many nuclear weapons if there is no civilian nuclear power program in the country; and it compares these times to those possible under different technical fuel-cycle configurations and various multinational and international arrangements overseeing the fuel cycle if there is civilian nuclear power.

Introduction

The large stocks and flows of nuclear materials associated with civilian nuclear energy programs require a prudent approach with respect to the breakout hazards of nuclear power in a future with very few or no nuclear weapons.

A civilian nuclear power program will unambiguously provide a country a foundation to produce fissile materials for nuclear weapons. It allows the country to train scientists and engineers, to build research facilities, to construct and operate nuclear reactors, and possibly also to learn techniques of reprocessing and enrichment that could later be turned to weapons uses. A civilian program could in this manner impel a country along a path of "latent proliferation," in which the country moves closer to nuclear weapons without having to make an explicit decision actually to take the final step to weapons, or at least to make transparent its intention to take such a step.[1]

The latent proliferation capabilities of civilian nuclear power will be a particular concern in a nuclear-weapon-free world. In a disarmed world, nuclear-power infrastructure could shorten the time for a state to acquire nuclear weapons. This

[1] H. A. Feiveson, *Latent Proliferation: The International Security Implications of Civilian Nuclear Power,* PhD Thesis, Princeton University, 1972.

time could be shorter for former nuclear weapon states seeking to reconstitute an arsenal if they retain former weapon facilities, albeit converted to peaceful purposes, and weapons design knowledge and experience. This concern, and the possibility of hedging strategies by powerful states based on a just-in-time nuclear arsenal capability, has led some analysts to conclude that reliance on nuclear power will not be tolerable in a weapon free world.[2] On the other hand, it can be argued that the breakout capability inherent in civilian nuclear power could offer stability, with states moving a non-weaponized deterrence ("virtual arsenals") based on civilian nuclear energy programs able to provide quickly fissile materials for a few or many nuclear weapons if others sought to break out of any disarmament agreement.[3]

Why Break Out and How?

The fundamental calculation of a country seeking to break out from a nuclear disarmament agreement would be to obtain nuclear weapons before others do—or before others can respond in any other way, i.e., possibly without acquiring nuclear weapons themselves—and to thereby achieve a meaningful political objective that is difficult to reverse. Such an objective could be to deter some sudden perceived security threat or to obtain some other significant advantage.[4]

In either case, the breakout country could then seek to obtain nuclear weapons either overtly or clandestinely. As we will see, the relative importance, credibility and probability of "success" of these two fundamentally different strategies are largely determined by the way nuclear energy will be used in the future.

A World Without Nuclear Energy

Let us imagine for a moment a world without civilian nuclear power, but one in which research reactors are used for scientific, industrial, medical, or other civilian purposes, and where there remains a widespread reservoir of knowledge of nuclear engineering. In such a world, a country wishing to obtain nuclear explosive materials could proceed in two ways: (a) construct a reprocessing plant and, if an existing research reactor was not used, also a dedicated production reactor to

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[2] T. B. Taylor, "Nuclear Power and Nuclear Weapons," July 1996, originally published by the Nuclear Age Peace Foundation, and reprinted in *Science & Global Security*, Vol. 13, 2005.

[3] J. Schell, *The Abolition*, Alfred A. Knopf, New York, 1984.

[4] S. D. Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb," *International Security,* 21(3), Winter 1996/97, pp. 54–86. Sagan offers several possible models and explanations for proliferation, but perceived security threats are likely to be the leading concern for a country leaving a disarmed world. In particular, the stigma of nuclear weapons in a nuclear-weapon-free world would be even stronger than it already is today. If so, explanations for the re-acquisition that emphasize the "symbolic" value of this weapon appear less relevant than they may have been in the past.

obtain plutonium; or (b) construct an enrichment plant to produce highly enriched uranium. As mentioned, this could be done clandestinely or overtly but, in either case, the country would have to pursue a similar series of steps. First, it would have to accumulate substantial amounts of natural uranium. The production of fissile material sufficient for a few nuclear weapons requires 10–20 tons of natural uranium or, assuming a typical ore grade, 10,000–20,000 tons of ore. Second, the country would have to build or re-activate adequate production facilities, reactors and reprocessing plants, or enrichment plants, requiring the training of large cadres of workers, some highly specialized.[5] Most of these activities would be highly visible, especially if robust verification arrangements are in place. If pursued clandestinely, this process would have to be carried out at a very low profile and could take many years—if it were possible at all without increasing the chances of detection to "unacceptable" levels.

In a nuclear-energy-free world, reconstituting a nuclear weapons program from scratch can be carried out much quicker if pursued overtly. Depending on the sophistication and previous experience of the country, the effort to produce the fissile material needed for a small stockpile of nuclear weapons could overall take 3–5 years. During that time, the country could in parallel design a nuclear weapon and to some extent build weapons without the nuclear explosive material. The U.S. Manhattan Project can serve as a reference point to illustrate this scenario and time estimate: the project was secret at the time, but would be equivalent to an overt breakout in a verified nuclear-weapon-free world.

Others, of course, would respond immediately to an overt breakout and *could* reconstitute a nuclear weapons arsenal in essentially the same time frame as the breakout country. In a nuclear-energy-free world, overt breakout from a disarmament agreement would therefore make little sense for almost any violator.

The Role of Nuclear Energy in an Overt Breakout Scenario

There are many options to deploy and use nuclear energy, including important technical choices with regard to reactor technologies and the nuclear fuel cycle, but also broader questions of ownership, management, and organizational structure of nuclear energy use. For the moment, we assume that all relevant facilities are under national control or managed such that the host state would be in a position to take them over and operate them successfully. We also assume that nuclear power is non-discriminatory, such that all countries will be in a position to deploy a preferred fuel cycle, or none will.

[5] Few vendors of research reactors exist today, and most countries would therefore have to acquire or re-acquire the capability to build nuclear reactors suitable for plutonium production. We also assume that the fuel used in the remaining research reactors (e.g. enriched to 20% in the isotope U-235) would not be attractive (in terms of quality and quantity) as source material in a breakout scenario.

The Closed Nuclear Fuel Cycle. If a country already had a reprocessing plant, and therefore routinely separated plutonium, it could obtain plutonium for weapons almost immediately. It might still take days or weeks to process the plutonium into weapon-usable forms; but the plutonium, once diverted, could be transported to some secret location where it would be safe from attack.

Reprocessing plants now in use employ a chemical process termed PUREX to separate the constituents of the spent fuel. As this process leads to a relatively pure stream of plutonium nitrate, separated from fission products and other transuranic elements, it has poor diversion-resistant qualities. As a result, the United States and a few other countries have considered alternative reprocessing technologies,[6] but neither of these technologies would alter significantly the time required for a country to obtain weapon-usable plutonium in an overt breakout scenario. Most importantly, all proposed reprocessing schemes reduce the radiation levels of the material by orders of magnitude to facilitate fuel fabrication (see Figure 1)—but therefore also lower the level of difficulty of separating pure plutonium from this mixture if desired.

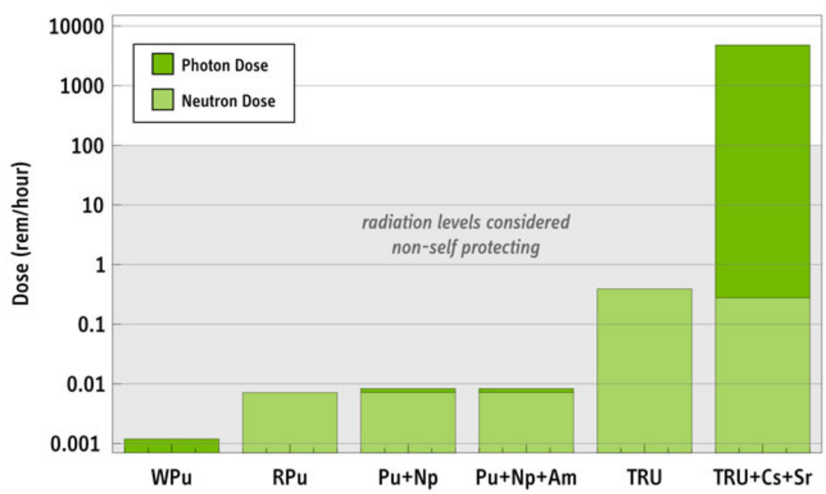

Figure 1. Radiation dose levels at one meter in air.[7]

In the case of plutonium recovered from spent fuel from light-water reactors that had achieved a target burnup of 33,000–50,000 MWd/MT, the material would be reactor-grade (50–60% Pu-239), which would not inhibit its use for weapons.[8] If the

[6] Alternative reprocessing technologies include aqueous processes, in which some of the transuranic elements would be precipitated out with the plutonium, and pyroprocessing technology, an electro-refining procedure that could also keep some of the transuranic and/or rare-earth elements with the plutonium.

[7] Based on R. Hill, "Advanced Fuel Cycle Systems: Recycle/Refabrication Technology Status," September 7, 2005.

[8] For a time, many believed that plutonium generated in commercial reactors could not be used for weapons since this grade plutonium has a relatively high fraction of the isotope Pu-240. The issue was addressed in a 1994 National Academy of Sciences study and later described in a 1997 U.S.

country, however, wanted weapon-grade plutonium (more than 90% Pu-239), it could time breakout such that the most recent 20-ton batch of fuel loaded to one or more of its power reactors is just reaching an average burnup of about 3000 MWd/MT(HM). At this point, the plutonium concentration in the fuel is about 2 kg/MT(HM) and a total of about 40 kg of weapon-grade plutonium could be discharged with each 20-ton batch of that burnup.[9] If deemed necessary, this fuel could be reprocessed without much delay due to the low irradiation level of 5–10% of the standard value.

The Standard Once-Through Nuclear Fuel Cycle. Light-water reactors are likely to continue to dominate nuclear power worldwide for the next several decades. The once-through fuel cycle, and indeed any of the fuel cycles now being realistically considered, will require substantial uranium enrichment over this period. Uranium enrichment today is still limited to a rather small set of suppliers, mostly nuclear weapon states, but an increasing number of countries is pursuing enrichment programs—or might decide to so in the future. The production of weapon-grade uranium could potentially be accomplished quickly if a country already possessed or hosted a uranium enrichment facility that was producing low-enriched uranium. For several reasons, gas centrifuge technology, which is now dominating the enrichment market, is well suited for a breakout nuclear-weapons program.[10] In particular, a centrifuge facility can be converted from the production of low-enriched uranium to that of weapon-grade uranium by batch recycling so that cascades did not have to be reconfigured. In this manner, the production of weapon-grade uranium could commence almost immediately as shown in Figure 2. Overall, given a national enrichment facility of the size, say, to fuel a typical one GWe LWR, the time to produce a few weapons-worth of HEU would be on the order of a few weeks.

An enrichment plant could possibly be disabled in time, i.e., before significant stockpiles of fissile material could be accumulated. Alternatively, a country could then move to acquire plutonium. With a reactor, a country will have a ready source of plutonium. Even if there are arrangements to send spent fuel to an international repository, it is likely that spent fuel will be kept on site at each reactor for several years. To obtain the contained plutonium, a country would have to reprocess the spent fuel. In an overt breakout scenario, it could do this by constructing a "quick

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Department of Energy Report, which concluded: "Virtually any combination of plutonium isotopes … can be used to make a nuclear weapon. […] In short, reactor-grade plutonium is weapon-usable, whether by unsophisticated proliferators or by advanced nuclear weapon states." *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives,* U.S. Department of Energy, DOE/NN-0007, Washington, D.C., January 1997, Box 3–1 (pp. 37–39), www.ipfmlibary.org/doe97.pdf.

[9] Numbers adapted from: A. Glaser, "Isotopic Signatures of Weapon-grade Plutonium from Dedicated Natural-uranium-fueled Production Reactors and Their Relevance for Nuclear Forensic Analysis," *Nuclear Science and Engineering,* September 2009.

[10] H. Wood, A. Glaser, and R. S. Kemp, "The Gas Centrifuge and Nuclear Weapons Proliferation," *Physics Today,* September 2008, pp. 40–45.

and dirty" reprocessing plant. This could be accomplished in a year or less. A relatively small reprocessing plant of a capacity of 50 metric ton heavy-metal per year could separate up to 500 kilograms of plutonium annually, or enough for a single bomb in a week or less.[11]

Nuclear Energy without Enrichment and Reprocessing. For completeness, let us finally consider a situation, in which both enrichment and reprocessing have been abandoned or, in other words, in which nuclear power has shifted to natural uranium fueled reactors.[12] Even is such a world, it would still be possible for a country to construct a "quick and dirty" reprocessing plant, as described above.

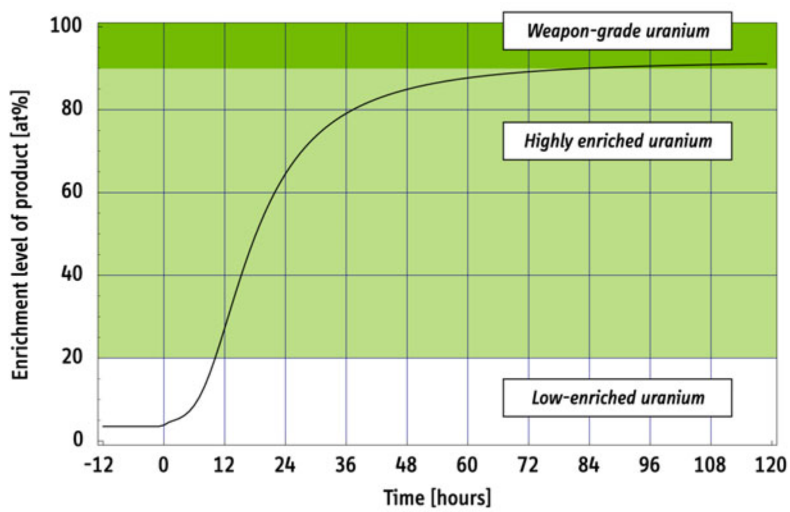

Figure 2. Enrichment level of the product recovered from a centrifuge cascade after two batch-recycling steps. In this simulation, at time zero, pre-enriched uranium (3.5%) is fed into three cascades connected in parallel. The output of these cascades reaches an enrichment level of 16.3%. This product is fed into a fourth cascade, which delivers weapon-grade uranium after about 3.5 days.[13]

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[11] Indeed, the possibility of the quick construction of a reprocessing plant was raised during the Carter Administration in a 1977 study by a group of technical experts at the Oak Ridge National Laboratory who presented the design of such a plant together with a flow sheet and an equipment list. The study sought to make the case that a country with a minimal industrial base could quickly and secretly build such a plant. See: D. E. Ferguson to F. L. Culler, *Simple, Quick Processing Plant,* Intra-Laboratory Correspondence, Oak Ridge National Laboratory, August 30, 1977; and: *Quick and Secret Construction of Plutonium Reprocessing Plants: A Way to Nuclear Weapons Proliferation?,* Report to the Comptroller General of the United States, EMD-78-104, October 6, 1978.

[12] Note that natural-uranium fueled reactors require significantly less uranium resources than light-water reactors operated on an once-through or on a single-pass MOX fuel cycle. If operated in a world, in which reprocessing has been phased out, this technology could be considered superior to the light-water reactor from a nonproliferation perspective. For a discussion, see for example: E. Lyman, "Envisioning a World without Uranium Enrichment," *48th Annual INMM Meeting,* Tucson, AZ, July 8–12, 2007.

[13] A. Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and their Relevance for Nuclear Weapon Proliferation*," Science & Global Security,* Vol. 16, Nos. 1–2, 2008*.*

The Role of Nuclear Energy in a Clandestine Breakout Scenario

An overt breakout generally does not appear an attractive strategy for a violator to pursue because others would be in a position to reconstitute a nuclear weapons arsenal at least equally fast if they deemed such a response necessary. A clandestine strategy may seem more attractive both because technical know-how can in principle be transferred to a parallel program and because legitimate nuclear activities create a "background noise," which can make detection of clandestine efforts much more challenging.

Acquiring fissile material clandestinely in a proliferation-vulnerable world can be pursued in two ways: either through protracted diversion of fissile material from a declared fuel-cycle facility, most likely plutonium from a reprocessing plant or other facility handling plutonium, or through a parallel program using the expertise in reprocessing or enrichment acquired in the declared program.

Even with a civilian nuclear power program in place, it would be difficult for a country to hide undeclared new production of plutonium.[14] Undetected diversion of already separated plutonium might be more possible. A clandestine centrifuge enrichment project might remain undetected for extended periods of time. Centrifuge plants need little electricity and have few emissions or other characteristic signatures, thus making detection extremely difficult.[15] If expertise in enrichment and reprocessing is unavailable, a clandestine program would be almost as difficult to carry out as in a nuclear-energy-free world. For example, it took Iran more than a decade to set up and develop first-generation centrifuge technology; eventually, of course, these efforts were detected before the technology was mature.

Given the above, the challenge of safeguarding nuclear power in a nuclear-weapon-free world is two-fold: (a) to deter overt breakout because it becomes essentially impossible for the violator to acquire nuclear weapons before others do and therefore neutralizing the rationale of the undertaking; and (b) to significantly increase the hurdles for a clandestine breakout, making the process much more time-consuming, difficult, costly, and visible, which ultimately increases the chances of timely detection of the effort.

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[14] *Global Fissile Material Report 2007,* International Panel on Fissile Materials, Princeton, NJ, October 2007, Chapter 9 (Detection of Clandestine Fissile Material Production), www.ipfmlibrary.org/gfmr07.pdf

[15] R. S. Kemp and A. Glaser, "The Gas Centrifuge and the Nonproliferation of Nuclear Weapons," pp. 88–95 in Shi Zeng (ed.), *Proceedings of the Ninth International Workshop on Separation Phenomena in Liquids and Gases (SPLG),* September 18–21, 2006, Beijing, China, Tsinghua University Press, 2007.

Institutions and Safeguards for a Nuclear-Weapon-Free World

To meet these challenges, several measures will have to be put in place. First, all facilities producing nuclear explosive materials would be shutdown or converted to civilian (or military, non-weapon) uses, and all stockpiles of nuclear weapons and weapon-usable materials in the military sector would be identified, monitored, and eventually eliminated in a verifiable manner. Similarly, all civilian facilities and stockpiles of nuclear explosive material would have to be identified and monitored.

Also, at a minimum, we must suppose that all, or almost all, civilian nuclear facilities would be placed under international safeguards, such as now implemented by the International Atomic Energy Agency (IAEA). Such safeguards would include inspections at declared nuclear facilities and the universal implementation of the Additional Protocol or of an equivalent arrangement authorizing the IAEA to look for undeclared, clandestine nuclear facilities.

This is a minimum structure for an institutional arrangement to safeguard nuclear power in a nuclear-weapon-free world, but important additional measures could also be imagined. In particular, regional and multinational arrangements to discourage national fuel cycle facilities, such as reprocessing and enrichment plants, appear achievable and could be effective, and some ideas for multinational arrangements have recently been put forward.[16]

A requirement that any new facilities be multinational raises questions about when and where they would be built and by whom. In addition, there are fundamental questions about what purpose is to be served by requiring nuclear facilities to be owned collectively by several states and how such a management structure can serve as a form of effective control over the use of such a facility.

A facility has to be located somewhere, regardless of who is a partner in it or has formal ownership and control, and the host state would generally have the capacity to nationalize this facility.[17] It can be argued that collective ownership works to create a potential political barrier to the host state seizing the plant for weapons purposes, as this would require expropriating property of other states or a multinational organization. The ability of the partners, or the international

[16] Y. Yudin, *Multilateralization of the Nuclear Fuel Cycle: Assessing the Existing Proposals,* UNIDIR/2009/4, United Nations Institute for Disarmament Research, New York and Geneva, 2009, www.unidir.ch, and: A. Glaser, *Internationalization of the Nuclear Fuel Cycle,* Commissioned Report for the International Commission on Nuclear Non-proliferation and Disarmament, ICNND Research Paper No. 9, February 2009, www.icnnd.org.

[17] A proposal put forward by Germany tries to overcome this dilemma. The host state would offer the territory, but a separate set of countries would then build and operate the enrichment plant on that site. Ideally, the host would have no experience with uranium enrichment and a hypothetical takeover of the plant somewhat less of a concern. For a discussion, see A. Glaser, *Internationalization of the Nuclear Fuel Cycle, op. cit.*

community more broadly, to prevent nationalization would be determined, however, by the military and economic power of the host state and its relationships with its partners and with the international system. This suggests that, to be of enduring value in a nuclear-weapon-free world, multinational ownership in which states can pick and choose their partners in nuclear projects may not be sufficient. As the world moves toward nuclear disarmament, to achieve a nuclear power system that is fully effective and truly nondiscriminatory, the establishment of an international authority to oversee and manage all the sensitive parts of the fuel cycle for all countries—notably enrichment and reprocessing—may be necessary.[18]

The above complex of institutional measures could be termed "proliferation resistant," in contrast to the situation where sensitive fuel cycle facilities remain under national control and are consequently "proliferation vulnerable." Table 1 summarizes some nominal timelines for the different fissile material production scenarios, distinguishing proliferation resistant and proliferation vulnerable arrangements.

	No Nuclear Energy	Proliferation Resistant	Proliferation Vulnerable
Clandestine	very long (if possible at all)	very long (on the order of 10 years)	1–2 years**
Overt Breakout	3–5 years	1–2 years*	very short (weeks)

Table 1. Nominal time estimates to produce fissile material for a small number of nuclear weapons. If a country attempted an overt breakout, other countries or the international community could respond (militarily or non-militarily) within a very short period of time. Overt breakout, especially in a proliferation-resistant world, therefore appears much less credible and "sensible" than a clandestine effort; *Assumes that reactors and possibly some spent fuel are under national control, but no access to enrichment or reprocessing plants; most likely, a "quick-and-dirty" reprocessing strategy would be most effective; **Assumes that enrichment or reprocessing plants exist in the country and that the country has the expertise to build and operate such facilities, which could be used to set up a parallel military program clandestinely; the chances of completing this effort before being detected varies with nature of the verification arrangements in place.

[18] This is not a new idea, of course, and goes back to the 1946 Acheson-Lilienthal proposal. Similar ideas were discussed in the 1970s when the creation of an International Nuclear Fuel Authority (INFA) was considered by the United States. More recently, some analysts have picked up the INFA concept as a strategy to resolve the crisis surrounding Iran's enrichment program: T. B. Cochran and C. E. Paine, "International Management of Uranium Enrichment," *International Meeting on Nuclear Energy and Proliferation in the Middle East,* Amman, Jordan, June 22–24, 2009.

The Transition to a Nuclear-Weapon-Free World

The discussion heretofore has focused on a nuclear-weapon-free world. But such a world would likely take a long time to achieve and it is important to ask what would be the impact of civilian nuclear power during the transition period.

During a transition period, the current nuclear weapon states would have access to large amounts of fissile materials recovered from dismantled nuclear weapons. These stockpiles might be placed under some type of international monitoring, but could be removed suddenly from monitoring if the host state decided to do so. During this period, therefore, the former weapons material would provide a quicker route to rearmament than the domestic civilian nuclear energy sector. For non-weapon states with a civilian nuclear power and fuel cycle infrastructure nothing much would be changed by the disarmament process in the weapon states. They would maintain the option of diverting materials from their civilian programs to weapons if the disarmament process somehow fell apart.

The key question then is whether the development and expansion of civilian nuclear power would make more difficult the achievement of a weapon-free world?

If the expansion includes a proliferation of fuel-cycle facilities to countries that now have no or only a negligible amount of nuclear power, then as the world moves toward nuclear disarmament, there would be several new countries with either stockpiles of nuclear explosive material or facilities to produce such material, which would have to be stringently accounted for and safeguarded. Especially if some of these countries were politically unstable or have questionable motives, the disarmament process could be severely undermined. It is therefore vital that the international community undertake efforts to forestall a proliferation of fuel cycle facilities.

Conclusion

Possession of civilian nuclear power would shorten the time required for a rogue country to break out of a disarmament agreement and produce some or many nuclear weapons. By the same token, such possession also would allow a more rapid deployment or redeployment of nuclear weapons by a country wishing to respond to the breakout country. The existence of a civilian nuclear program would probably also make more possible, though still difficult, a clandestine program by a rogue country to produce nuclear explosive material, which if successful could shorten the time for the international community to react against the country.

How important these shortenings of times to break out and to respond would be would depend upon considerations beyond the issues of civilian nuclear power alone: How a rogue cheater would plan to use a fleeting monopoly of nuclear weapons, what enforcement mechanisms were built into the disarmament treaty, and how other countries would actually respond to the cheater to ensure compliance with any disarmament treaty.

If civilian nuclear power were phased out in parallel with nuclear weapons disarmament and before a nuclear-power renaissance spread nuclear power to many more countries, it would have some security advantages in making it more difficult and time-consuming for the scores of countries without any nuclear infrastructure today to launch a nuclear weapon program from scratch. For this reason, even if civilian nuclear power is not phased out, it is important to limit to the extent possible any proliferation of national nuclear fuel cycle facilities, such as centrifuge plants.

Reprocessing plants, by producing nuclear explosive material directly or nearly directly, present the greatest dangers in a nuclear-weapon-free world. They provide the most plausible route to get weapon-usable material, and they shorten the time for a breakout to days. While other countries could then respond also in days, this would give little time for other responses, including various international actions and sanctions to take place.

For this reason, it is essential as an adjunct to any nuclear disarmament treaty to create international institutions to operate and safeguard both reprocessing plants (if they exist) and spent fuel repositories. The lengthy transitional period to effect disarmament should also be used to move as many parts of the fuel cycle as possible from national to multinational and international controls.

Finally, without new rules for managing nuclear power, its global expansion will impose intolerable proliferation risks; but, as has been widely noted, non-nuclear states appear increasingly opposed to acceptance of such rules unless the nuclear weapon states more vigorously pursue nuclear disarmament.[19] Therefore, if it is generally deemed critical that civilian nuclear power be expanded on a large scale to combat global warming, the establishment of a weapon-free world could lend vital support to such a nuclear renaissance. For in a world of nuclear disarmament, the incentives for rogue countries to acquire nuclear weapons would be lessened, the myriad of discriminatory features that now dominate nonproliferation institutions would be removed, and international measures to secure compliance with international agreements would be more assured.

[19] George Perkovich and James Acton, *Abolishing Nuclear Weapons*, Adelphi Paper 396, International Institute for Strategic Studies, Routledge, 2008.