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The myth of proliferation-resistant technology

The specter of nuclear proliferation must be understood as both a political issue and a technological one. For the intent of would-be proliferators needs to be addressed together with the science.

BY JAMES M. ACTON

Writing in the journal *Science* in 1968, ecologist Garrett Hardin observed the existence of a category of problems for which there was no technical solution. Focusing on the challenge of feeding a burgeoning global population, Hardin argued, "It is fair to say that most people who anguish over the population problem are trying to find a way to avoid the evils of overpopulation without relinquishing any of the privileges they now enjoy. They think that farming the seas or developing new strains of wheat will solve the problem—technologically. I try to show here that the solution they seek cannot be found."[1]

Forty years on, Hardin's central thesis—that it is impossible to solve a political problem with a technical solution—is still salient and applicable to more than just managing population. At the moment, a number of initiatives promote a technological approach to solve—or at least ameliorate—the problem of nuclear proliferation through the misuse of civilian nuclear facilities (particularly reactors and reprocessing plants). Their aim is to make novel nuclear technologies "proliferation resistant."

There is nothing wrong *per se* with technology that makes the diversion of nuclear material harder or more likely to be detected. Yet a failure to appreciate fully the political dimension of nonproliferation risks makes the concept of proliferation resistance at best irrelevant and at worst counterproductive. For the anticipated global expansion of nuclear energy to not exacerbate nuclear insecurity, a more politically savvy approach to proliferation resistance is needed.

The political limits of a technological approach. Interest in new nuclear technologies may be more restricted than interest in

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nuclear energy, but it is nonetheless at a 30-year high.[2] Even as the Obama administration reins in overly ambitious plans for the early deployment of fast reactors and advanced reprocessing technologies in the United States, it has made clear that domestic research into these technologies will continue.[3]

Meanwhile, other nations are pushing on with ambitious nuclear development plans, both individually and in concert. Research into new reactor technologies, including fast reactors, is being coordinated within two multilateral frameworks, the U.S.-led Generation IV International Forum (GIF) and the International Atomic Energy Agency (IAEA)-led International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). Extensive research into advanced recycling technologies also is ongoing.[4] France, the United States, and others are investigating new aqueous reprocessing schemes such as GANEX and UREX+. Unlike conventional reprocessing, these technologies do not separate pure plutonium but instead leave it mixed with other radioactive elements. This is supposed to complicate the task of any state seeking to weaponize this material. South Korea and Canada remain interested in the DUPIC fuel cycle, in which spent fuel from pressurized water reactors is used to power heavy water moderated CANDU reactors. And most controversially, South Korea is hoping to develop pyroprocessing—a reprocessing technology designed to produce metallic fuel for fast reactors by separating plutonium and uranium from spent fuel dissolved in molten salt with an electric current.

All of these initiatives stress the importance of nonproliferation, at least rhetorically, and emphasize those characteristics of the technologies under development that contribute to proliferation resistance, generally defined as, “that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by [a state] seeking to acquire nuclear weapons or other nuclear explosive devices.” Another important element of the concept is that “the degree of proliferation resistance results from a combination of, inter alia, technical design features, operational modalities, institutional arrangements, and safeguards measures.”[5] Proponents of these technologies also typically recite the catechism that proliferation resistance involves both intrinsic barriers (technical characteristics of the system) and extrinsic barriers (safeguards).

The growing consensus among scientific experts, both inside and outside of governments, is that the technical, intrinsic aspects of proliferation resistance have been significantly oversold.[6] In contrast, its political problems are underappreciated, but no less significant.

One example is weaknesses in the extrinsic barriers that mean states probably could avoid consequences if they were to bypass the intrinsic barriers. The technologies that comprise the DUPIC fuel cycle provide a good illustration. At a tactical level, DUPIC offers a number of nonproliferation benefits. Heavy water reactors are generally seen as more proliferative than light water reactors, in part because their spent fuel contains plutonium that can more easily be extracted and used in weapons. Feeding heavy water reactors with high burnup spent fuel from pressurized light water reactors reduces the attractiveness of the plutonium they produce. Moreover, in the DUPIC process, the spent fuel from the pressurized water reactors is mechanically ground up, not dissolved, so it is considerably harder to subvert for military ends than it would be using conventional aqueous reprocessing.

Reprocessing a reactor's blanket and driver together could improve proliferation resistance by mixing high-quality blanket plutonium with lower-quality driver plutonium. Yet a state could simply circumvent this obstacle by deciding to reprocess the blanket and driver separately. There is no technical, legal, or political barrier to doing so.

At a strategic level, however, the concept of DUPIC is more problematic. Canada, the only commercial supplier of heavy water reactors, hopes that if DUPIC is successfully commercialized, it will help revive flagging interest in its CANDU reactors. If successful, however, this would lead to a greater number of states having a more attractive option for proliferation. After all, states buying CANDUs are unlikely to commit to fueling them *only* with spent fuel from pressurized water reactors. A state could simply decide to run its CANDUs on natural (or slightly enriched) uranium. This would be perfectly legal and would probably be seen as entirely legitimate. On the off chance the nation felt the need to justify a decision to stop running its CANDUs on spent pressurized water reactor fuel, it could always mutter something about economic advantages or argue that its DUPIC facility was in need of repairs. In this sense, DUPIC actually could reduce the barriers to proliferation. This is the kind of problem missed by looking at proliferation with only a narrow technical focus.

Political problems have bedeviled recent efforts to build proliferation resistance into the global nuclear architecture. When the Bush administration launched the Global Nuclear Energy Partnership (GNEP) in 2006, it specifically advocated for the development of fast *burner* reactors capable of consuming more transuranic material than they produced—a reflection of the waste-management concerns that motivated the Bush administration's interest in closed fuel cycles.[7] The administration also argued that its interest in burner reactors was consistent with GNEP's nonproliferation goal since, by themselves, burner reactors pose relatively few opportunities for misuse. (This argument, however, ignores the reprocessing technology needed to produce fuel for burner reactors—a point to which I return later.)

The fast burner reactor is very similar, however, to the fast *breeder* reactor. In a breeder, the reactor core (consisting of a fission "driver" of plutonium) is surrounded by a "blanket" of uranium that is irradiated to create, or breed, more plutonium, which can be reprocessed and used to make more fuel. But because this material also is extremely attractive for use in nuclear weapons, breeder reactors pose significant proliferation concerns. Moreover, the challenges to the development of burners and breeders are similar; U.S. support for the burner inevitably contributes to the development of its more proliferative sibling, the breeder. Indeed, even before GNEP was launched, the GIF 2002 road map acknowledged, in deference to the different priorities of the participating states, that all fast reactor designs under consideration could equally contribute to the development of breeders or burners.

Efforts to make breeder reactors more proliferation resistant are unfortunately little more than symbolic. For instance, a discussion of the proliferation resistance of fast reactors in a special issue of the *ESARDA Bulletin* (published by the well-respected European Safeguards Research and Development Association) states that "blanket assemblies are considered to be processed together with driver assemblies."[8] Yes, reprocessing a reactor's blanket and driver together could improve proliferation resistance by mixing high-quality blanket plutonium with lower-quality driver plutonium. Yet a state could simply circumvent this obstacle by deciding to reprocess the blanket and driver separately. There is no technical, legal, or political barrier to doing so.

The *ESARDA Bulletin* article goes on to mention that "a concept that generates low-grade plutonium in discharged blankets" was under investigation, although it does not describe the idea any further. Typically, however, such concepts involve "doping" fresh fuel with materials that complicate weaponization. Doping fresh fuel for light water reactors with americium 241, for instance, leads to an increased fraction of plutonium 240 on discharge.[9] To be effective, however, such concepts would require *all* foreign fuel suppliers to provide only doped fuel and for the state that owns the reactor—if it also is capable of producing fuel—to refrain from producing undoped fuel. Even leaving aside the economic costs of doping, suppliers today lack the political will to forge such an agreement, and nations are unlikely to accept any limits on their sovereign right to produce whatever kind of fuel they want. In practice, because the emission of gamma radiation from americium 241 complicates fuel handling, commercial entities would strongly oppose such an agreement. Pushing on with the development of such novel fuels and reactors that are only proliferation resistant if states choose to use them in the "right" way could increase the opportunities for proliferation, unless political measures to curtail and deter misuse are simultaneously and successfully pursued.

Enrichment and economics. Advocates of GNEP have recently broadened the concept of proliferation resistance to include more than just technical approaches meant to complicate the diversion and misuse of nuclear material. The context for their argument is the vision that a small number of "fuel supplier" nations could provide comprehensive fuel services (e.g., the provision of fresh fuel and the removal of spent fuel) to all the others. In the original vision of GNEP, one of several proposed fuel-supply arrangements, only states that already had enrichment and reprocessing technologies would be eligible to become suppliers and other "consumer nations" were not to enrich or reprocess, although this requirement was later dropped when no state agreed to it.

> Slowing the rise in demand for enrichment services—so the argument goes—makes the enrichment business less lucrative and therefore less likely to attract new entrants. But the principal barrier to entering the enrichment market—the large research and development costs of building economically viable centrifuges—is already high enough to deter anyone looking to make money.

Against this background, the Energy Department has argued that despite the potential ineffectiveness of intrinsic proliferation-resistant measures, the closed fuel cycle has positive externalities—benefits that accrue to parties not directly involved in the transaction—that, on balance, could promote nonproliferation.[10] Energy argues that closing the fuel cycle by recycling plutonium and using it as fuel would have the positive externality of reducing the amount of uranium enrichment needed for each unit of electrical energy produced.[11] Slowing the rise in demand for enrichment services—so the argument goes—makes the enrichment business less lucrative and therefore less likely to attract new entrants.

One problem with this line of reasoning is that the principal barrier to entering the enrichment market—the large research and development costs of building economically viable centrifuges—is probably already high enough to deter anyone looking to make money. Indeed, the two companies planning to enter the global centrifuge business have been able to do so only by shortcutting the R&D process. Areva simply bought the technology off the Anglo-Dutch-German consortium Urenco under a "black box" arrangement, and the U.S. Enrichment Corporation (formally known as USEC) program is built on the back of an extensive government research effort that was cancelled in 1985. Furthermore, the price of enrichment is likely to drop with the retirement of expensive gaseous diffusion facilities, further increasing the barriers to entry.[12]

If demand for enrichment rises, it is likely to be much cheaper for existing suppliers to expand capacity than for new players to enter the market. Thus, there are unlikely to be any major new enrichment firms, whether or not reprocessing becomes widespread.

The second problem with Energy's argument is that none of the small-scale enrichment programs that have been the cause of so much recent concern were started with the goal of making money. Some programs, such as those in Pakistan, Iraq (prior to 1991), and purportedly North Korea, were unquestionably set up to produce highly enriched uranium for nuclear weapons. Iran's enrichment program appears, at the very least, to be a nuclear weapons hedging option. A nuclear weapons option also drove Brazil's program, which has been sustained largely for prestige. It is implausible to suggest that reducing the global demand for enrichment services by closing the fuel cycle would have altered any of these states' decisions.

A somewhat more credible argument is that reducing the demand for enrichment might reduce the pressure on states with energy security concerns to initiate their own enrichment programs. This argument might have held in the early- to mid-1970s when the United States was the only commercial supplier of enrichment services to the West and used energy-intensive gaseous diffusion technology. At that time, demand for enrichment services exceeded supply, the process of expanding capacity was slow, and it was politically unattractive for the United States to increase output.[13] Many states were deeply worried about the security of supply. Yet the United States was not in a position to offer credible fuel supply guarantees—even if it had been inclined to do so.

The situation is different today. Because centrifuges can be produced quickly, enrichment suppliers can expand their capacity faster than reactors can be built. Thus, supply shortfalls appear unlikely for the foreseeable future. This is not to say that countries don't have supply concerns. Indeed, some do worry about politically motivated disruptions to their supply, yet this uncertainty cannot be effectively addressed by the technical "fix" of reducing demand for enrichment services. The primary challenge in orchestrating fuel supply guarantees is the uneasiness of potential recipients about their terms, not the reluctance of potential supplier states, weary of an impending enrichment shortfall, to offer them.

Reprocessing and take back. Another advertised benefit of reprocessing, particularly advanced methods such as UREX+, is its potential to contribute to spent fuel management by reducing the volume, radiotoxicity, and heat of high-level waste.[14] Advocates of reprocessing, particularly in the Energy Department, argue that by simplifying waste management, reprocessing could facilitate the nonproliferation holy grail of spent fuel "take back" or "take away"—that is, the removal of spent fuel by the state that supplied it or by a third party.[15] Take-back provisions would undoubtedly benefit nonproliferation. They would reduce the domestic pressures on states to develop reprocessing as a waste management strategy thereby avoiding "plutonium rivers" as well as preventing the buildup of large volumes of spent fuel that could become "plutonium mines." The problem is that reprocessing is unlikely to decrease public opposition to importing spent fuel and may actually increase it.

Governments, regulators, and the nuclear industry need to recognize the political problems associated with the concept of proliferation resistance and efforts to employ technologies in its name.

At issue, once again, is whether a technical solution can solve what is essentially a political problem.[16] Public opposition to importing spent fuel operates at various levels.[17] Many people have a visceral objection to turning their state into a nuclear "dump." Some also believe that countries should deal with their own waste—a form of the "polluter pays" principle. These concerns are simultaneously exacerbated by a lack of trust in nuclear regulators. Advanced reprocessing technologies solve none of these objections.

Reprocessing is additionally a controversial technology in itself. The planning process for any kind of reprocessing facility in the United States (and many other countries) would unquestionably be met with intense opposition on environmental grounds and probably with numerous legal challenges. This could slow the development of a credible waste-management strategy, making take back even less likely.

Worse still, a decision by the United States to develop reprocessing could encourage other states to do likewise.[18] Even if the United States and other advanced nuclear states were to avoid separating pure plutonium, others seeking to close the fuel cycle wouldn't necessarily select an identical separation technology. After all, PUREX technology, which was originally designed to produce pure plutonium for the Manhattan Project, is relatively simple, widely documented, and entirely legal, and therefore, a more attractive choice than, say, UREX+ for less advanced states looking to start reprocessing. Moreover, it is unlikely that all the advanced nuclear states would agree to use only advanced reprocessing technologies. Japan, for example, has only recently finished construction of the Rokkasho Reprocessing Plant, which is based on slightly modified PUREX technology. Given that the plant is expected to operate until at least 2045 and that it cost $20 billion to build, the Japanese are unlikely to abandon it and switch to an alternative technology.[19]

Where next? Governments, regulators, and the nuclear industry need to recognize the political problems associated with the concept of proliferation resistance and efforts to employ technologies in its name. Ongoing work to develop methodologies to assess proliferation resistance and allow the systematic and unbiased comparison of different fuel cycle choices are an important part of this process. The GIF evaluation methodology, for instance, involves identifying specific proliferation pathways in a nuclear energy system.[20] If done properly, such an evaluation would presumably quickly identify the problem of, say, basing the proliferation resistance of a breeder reactor on the hope that users will reprocess the drivers and blankets together. States can and should build upon this start.

First, methodologies for assessing proliferation resistance must be designed to independently evaluate fuel-cycle technologies anew, rather than to provide an opinion that simply defends choices that have already been made. For instance, the French nuclear services giant Areva—a strong supporter of reprocessing—developed a methodology called SAPRA, or Simplified Approach for Proliferation Resistance Assessment, which is based on scores assigned by a panel of experts. As might be expected, SAPRA concluded that the "[proliferation resistance] indexes of front end and back end are comparable, with or without reprocessing," while the more transparent and systematic GIF evaluation methodology reached the opposite conclusion.[21] An important first step, therefore, is for states to agree on a common, unbiased, and transparent approach to assessing proliferation resistance. Ideally, the IAEA would take the lead in this process and, indeed, it has been developing a methodology for assessing proliferation resistance within INPRO. Given that the IAEA never criticizes states' fuel cycle choices, however, it's not clear whether it's capable of leading this effort effectively.

Second, the development of proliferation-resistant methodologies cannot be a purely technical exercise. It must be a collaboration between natural and political scientists so that the kinds of political problems discussed in this article are addressed. In this regard, the United States is ahead of the IAEA or Areva with the "policy effects" approach that it outlined in its "Draft Nonproliferation Impact Assessment." Still, U.S. arguments about curtailing the spread of enrichment facilities by reducing uranium demand and using reprocessing to facilitate spent fuel take back rest on questionable political assumptions, leaving plenty of room for improvement.

Finally, and most importantly, governments and regulators must give proliferation-resistant assessments due weight in nuclear energy decisions. In spite of claims to the contrary, proliferation concerns are marginalized at the moment. The GIF road map, for example, defines four goal areas: sustainability, economics, safety and reliability, and proliferation resistance and physical protection.[22] These are further subdivided into more specific goals, which are considered to be equally important. Only one of these goals relates to nonproliferation, compared to two each for sustainability, economics, and safety and reliability. Whether deliberate or not, this weighting effectively relegates the importance of nonproliferation. Instead, it should be up to politicians to decide on the relative importance assigned to goals such as nonproliferation and economics. This is not a task to be delegated to technical working groups that tend to lack a broader perspective.[23] Proliferation is a political problem. If proliferation resistance is to be a worthwhile concept, then political considerations must be built into every stage of its assessment. ■

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NOTES

1. Garrett Hardin, "The Tragedy of the Commons," *Science*, vol. 162, no. 3859, pp. 1,243–1,248 (1968). Available at http://www.sciencemag.org/cgi/reprint/162/3859/1243.pdf.

2. For an overview, see the International Atomic Energy Agency (IAEA), *Nuclear Technology Review 2008* (Vienna: IAEA, 2008), section B and annexes IV and VI. Available at http://www.iaea.or.at/Publications/Reports/ntr2008.pdf.

3. Dipka Bhambhani, "DOE to End GNEP, Continue Research under AFCI," *Nuclear Fuel*, April 20, 2009, p. 1.

4. IAEA, *Nuclear Technology Review 2008*, Annex IV.

5. John Carlson, "Introduction to the Concept of Proliferation Resistance" (Research Paper No. 8, Revised: International Commission on Nuclear Non-Proliferation and Disarmament, January 3, 2009), p. 5. Available at http://www.icnnd.org/latest/research/Proliferation_Resistance.pdf.

6. See, for example, Jungmin Kang and Frank von Hippel, "Limited Proliferation-Resistance Benefits from Recycling Unseparated Transuranics and Lanthanides from Light Water Reactor Spent Fuel," *Science and Global Security*, vol. 13, no. 3, pp. 169–181 (2005). Available at http://www.princeton.edu/sgs/publications/sgs/pdf/13_3%20Kang%20vonhippel.pdf. Also see, Office of Nonproliferation and International Security (ONIS), *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives* (Washington, D.C.: ONIS, 2008), pp. 67–70. Available at http://nnsa.energy.gov/nuclear_nonproliferation/documents/GNEP_NPIA.pdf.

7. Energy Department, "GNEP Element: Develop Advanced Burner Reactors," February 6, 2006. Available at http://www.energy.gov/media/GNEP/06-GA50035f_2-col.pdf.

8. F. Sevini, G. G. M. Cojazzi, and G. Renda, "Proliferation Resistance and Physical Protection Robustness Characteristics of Innovative and Advanced Nuclear Energy Systems," *ESARDA Bulletin*, no. 39, p. 14 (October 2008). Available at http://esarda2.

jrc.it/db_proceeding/mfile/B_2008-039-03.pdf.

9. The presence of plutonium 240 complicates weaponization because its high neutron emissions can initiate a nuclear weapon before maximum criticality is reached. Most experts, however, contend that an increase in plutonium 240 in the fuel from americium 241 doping would be too modest to make a significant difference. Another example of doping is in the Radkowsky thorium reactor, where natural uranium is added to thorium-bearing fuel rods so that pure uranium 233 is not produced and enrichment would be required to make weapons-usable uranium. In this case, however, the natural uranium also contributes to the power of the reactor so it is less clear if fabricating thorium fuel rods without it would be feasible. See Mujid Kazimi, "Thorium Fuel for Nuclear Energy," *American Scientist*, vol. 91, no. 5 (2003). Available at http://www.americanscientist.org/issues/feature/2003/5/thorium-fuel-for-nuclear-energy; also see Alex Galperin, Paul Reichert, and Alvin Radkowsky, "Thorium Fuel for Light Water Reactors—Reducing Proliferation Potential of Nuclear Power Fuel Cycle," *Science and Global Security*, vol. 6, no. 3 (1997) pp. 265–290. Available at http://www.princeton.edu/sgs/publications/sgs/pdf/6_3galperin.pdf.

10. ONIS, *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives*.

11. ONIS, *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives*, chap. 6. This argument is also implicit in the often-heard claim that a nonproliferation attribute of fast reactors is their use of natural uranium.

12. This assumes that the enrichment market is reasonably competitive. With three or four major players (Areva, TENEX, Urenco, and possibly USEC), this is probably a reasonable assumption.

13. Michael J. Brenner, *Nuclear Power and Non-Proliferation* (Cambridge: Cambridge University Press, 1982), chap. 1.

14. U.S. Committee on the Internationalization of the Civilian Nuclear Fuel Cycle; Committee on International Security and Arms Control, Policy, and Global Affairs; National Academy of Sciences; and National Research Council, *Internationalization of the Nuclear Fuel Cycle: Goals, Strategies, and Challenges* (Washington, D.C.: National Academies Press, 2009), p. 83. Available at http://books.nap.edu/catalog.php?record_id=12477.

15. ONIS, *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives*, chap. 6.

16. See also, James M. Acton, "Nuclear Power, Nuclear Disarmament, and Technological Restraint," *Survival*, article forthcoming.

17. Ian Holland, "Waste Not Want Not? Australia and the Politics of High Level Nuclear Waste," *Australian Journal of Political Science*, vol. 37, no. 2 (July 2002), pp. 283–301.

18. Acton, "Nuclear Power, Nuclear Disarmament, and Technological Restraint."

19. World Nuclear Association, "Nuclear Power in Japan." Available at http://www.world-nuclear.org/info/inf79.html (August 2009); International Energy Agency, *Energy Policy of IEA Countries: Japan, 2009 Review* (Paris: IEA, 2008), p. 172.

20. The Proliferation Resistance and Physical Protection Evaluation Methodology Expert Group of the Generation IV International Forum, "Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems," (OECD Nuclear Energy Agency for the Generation IV International Forum, November 30, 2006). Available at http://www.gen-4.org/Technology/horizontal/PRPPEM.pdf.

21. Dominique Greneche, "A Practical Tool to Assess the Proliferation Resistance of Nuclear Systems: The SAPRA Methodology," *ESARDA Bulletin*, no. 39 (October 2008), p. 45. Available at http://esarda2.jrc.it/db_proceeding/mfile/B_2008-039-07.

pdf; ONIS, *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives*, pp. 67–70.

22. U.S. Energy Department Nuclear Energy Research Advisory Committee and the Generation IV International Forum, "A Technology Road Map for Generation IV Nuclear Energy Systems," (December 2002), pp. 9–10. Available at http://gif.inel.gov/roadmap/pdfs/gen_iv_roadmap.pdf.

23. Acton, "Nuclear Power, Nuclear Disarmament, and Technological Restraint."

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