Thoughts on Proliferation and Security Risks

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Abstract

U.S. policy and programs for commercial nuclear power should be guided by economic analysis and choice, including the internalization of costs of barriers to proliferation for any technology and fuel cycle not proof against proliferation (and that is all of them). Domestic suppliers should not be given preference over foreign sources, but loans and subsidies should reflect objective estimates or risks and benefits—not the kind of automatic AAA rating that polluted the mortgage-backed securities bubble. The decision process should recognize "proliferation resistant" as a slogan, not a description, and *the U.S. should reject reprocessing* of LWR fuel, while encouraging dry-cask storage for 100-200 years with realistic and imaginative evaluation of the risks of attack, and with the recognition of possible, if unlikely, reprocessing of that spent fuel when the technology and economics favor it. The United States *should lead in the supply of LWR fue*l under conditions of *prompt takeback* and commitment to interim dry-cask storage and *eventual regional commercial, competitive disposal in mined geologic repositories*. It should do the research and demonstration to *benchmark current costs of acquiring uranium from seawater*, where there exist 4 billion tons—enough to support a 30-fold expansion of LWRs for 2,000 years—while exploring means to reduce future costs of seawater uranium. The United States should help *initiate a cooperative world program to analyze and simulate several types of breeder reactors, complete with their detailed individual fuel cycles*, to result in the eventual building of a prototype if it can be established to be safe and economically competitive with the common LWR. If breeder reactors are to supplant the world's "burner" reactors, their rapid expansion will need to be fueled by U-235 from large-scale enrichment plants.

Discussion[1]

I welcome the opportunity to provide my thoughts, having considered the following questions:

1. What major policy and technical tools exist to reduce proliferation risk, and how might U.S. domestic fuel cycle policy influence the effectiveness of these tools?
2. How can proliferation risk be assessed to support policy decisions?
3. What obligations should the U.S. assume for IAEA safeguards on new nuclear infrastructure?
4. What resources are needed to develop new policies and tools to manage and reduce proliferation risk?
5. Can and should physical protection for nuclear facilities and materials be risk-informed?
6. What should be the expectations for improved security design for new nuclear infrastructure? How should one resolve potential conflicts between security and safety?

In considering the specific questions, it is too easy to lose sight of the nature of the proliferation problem. Although probabilistic risk assessment (PRA) and even probabilistic safety assessment (PSA) can be useful, they are far from the key elements of a program that will reduce nuclear proliferation risks worldwide.

Proliferation is of two types—national or subnational. At the time of the writing of the Ford-MITRE Study (1977), “Nuclear Power: Issues and Choices,” of which I was a member, the national proliferation risk was dominant in our consideration and those of others. However, during the lifetime of those reactors, it was certainly possible and has come to pass that subnational risks have become very important.

National proliferation risks, even for relatively democratic societies, include the potential consideration of the future option of nuclear weapons to that society or national entity. Given the great value placed on nuclear weapons by most of those who possess them, it seems only rational and responsible for a national government to make significant expenditures to understand how to build and acquire materials for nuclear weapons in order to make an informed judgment at some time in the future whether to acquire them. But this rationalistic approach can lead to a large latent capability to build nuclear weapons, and most nations judge the acquisition of nuclear weapons to be more hazard than benefit, and South Africa, which built some 6 nuclear weapons but eventually destroyed them and joined the Nonproliferation Treaty (NPT) as a non-nuclear-weapon state.

Subnational proliferation can be a matter of political faith or even of nihilism, with some entity judging that the capability for destruction by means of nuclear weapons will help it pursue its political goals, whether they involve the destruction of vast numbers of people, of wealth, or the command of societies.

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[1] I endorse the informative and authoritative testimony to the Commission by Matt Bunn and Frank von Hippel.

These goals can be facilitated by the choice of fuel cycle anywhere in the world. A society that cannot maintain the rule of law in general would be a ripe source for weapon-usable materials if it had a fuel cycle that would make them available in compact form as a result of the reprocessing of LWR fuel, such as the plutonium oxide in France or Japan or the United Kingdom, without the accompanying protective emission of penetrating radiation.

Because the decisions of the BRC are perforce about the FUTURE, it is important to note that the world already has a tremendous proliferation potential that arises from the nexus of increasing and increasingly disseminated knowledge of nuclear weaponry, expanding and improving industrial technology in general, and the accumulation of weapon-usable material in enormous amounts. The world's 300 equivalent full-size reactors each produce on the order of 0.2 tonne of Pu per year, which at a generous 10 kg of this "reactor-grade plutonium" per nuclear weapon would correspond to 20 potential weapons per reactor year or on the order of 6000 potential weapons per year. But it is not the highly radioactive spent fuel that is the major proliferation hazard, but the more directly weapon-usable separated Pu that is not self-protecting by virtue of its intense emission of gamma rays, as is the case with the spent fuel.

It is unreasonable to imagine that any terrorist organization is likely to be able to steal a large fraction of the accumulated plutonium in spent fuel, but it is entirely reasonable to imagine that such an organization could make off with 20 of the 2-kg welded steel cans in which the plutonium oxide is placed after the extremely clean separation from fission products in the conventional PUREX process. Direct terrorist attack to acquire the weapon-usable materials is not the only threat; violent criminal gangs motivated by financial gain are also a problem.

So it is crucial to protect the existing separated weapon-usable material until it is consumed or moved to permanent disposal, for which protection should be simpler and less expensive. Similarly, it will be necessary to protect appropriately the spent fuel that is inherently largely self protecting because of the intense gamma radiation field and the relatively low (about 1%) concentration of Pu.

I turn now to the key elements that I believe most limit proliferation.

A strong context of rational economic analysis and choice would be helpful, in which the costs of proliferation are internalized by setting a uniform standard, such as the Stored Nuclear Weapon Standard for weapon-usable HEU or separated plutonium, with the required levels of guns, guards, policies, and funds. A mechanism should be established by which a facility operator contributes to the IAEA funds adequate for the inspection and monitoring of the facility and the process, which would give the operator an incentive to adopt approaches to operation and to monitoring that would minimize the cost.

To minimize proliferation risk, designers, operators, investors, and builders of nuclear reactors and the nuclear fuel cycle must be informed of the proliferation potential. However, difficulties in implementing these approaches are obvious. The "economic analysis and choice" is distorted by politics, subsidy, and the like. The benefit to society is the aggregate of the benefit to various sectors, and given that much of what passes for economic activity is devoted to taking money from another sector rather than creating wealth, the future of this approach is not very bright.

As for risk assessment and information, the difficulty was evident in 2002 when I was a coauthor of the National Academies of Sciences volume, "Making the Nation Safer: The Role of Science and Technology in Countering Terrorism. Reactor operators and builders stated that they were unaware of the risks, because they did not have security clearance and the U.S. government could not legally inform them of the hazards.

Physically, national proliferation and subnational proliferation would be impeded by minimizing the amount of reactor-irradiated material in the using country, and using types of fresh fuel from which weapon-usable material can be obtained only by further enrichment.

An example is the once-through fuel cycle for LWRs, in which the spent fuel from the reactor would be kept for a few years in pool-type storage at the reactor, and then transferred to a permanent geologic repository or to dry-cask interim storage for 100 years if necessary—preferably away from the reactor site. This should be accompanied by a limited extraterritoriality granted to IAEA and some U.N. organization so that in civil emergency a world presence could help ensure the security of the fuel. Ultimately, disposal should be in regional, commercial, mined geologic repositories that would be regulated by IAEA in order to allow commercial competition with the assurance of environmental, safety, and security standards.

Technically, such repositories could, after sufficient research, be created in the seabed, but national and international security would need to be maintained against the unauthorized retrieval of material from the seabed. Furthermore, various international agreements would have to be modified to permit this approach.

Other approaches to disposal of excess weapons plutonium relate to some extent to the disposition of spent reactor fuel[2]. In particular, Appendix C, "Nonreactor, Nonrepository Disposal of Excess Weapons Plutonium: Technical Issues" describes five other options, and ultimately dismisses on technical grounds all but deep boreholes and the sub-seabed approach as possibilities, in addition, of course, to the mined geologic repository.

Proliferation is coupled also with the front end of the fuel cycle, first in the use of enrichment technology that would be effective in producing also highly enriched uranium (HEU) for weapon purposes. This is traditionally handled by non-nuclear weapon states members of the NPT with agreements that limit and control the enrichment to the LEU range for reactor fuel. Even for a process incapable of being used to enrich to the HEU range, it is important to recognize that almost 70% of the "separative work" has already been invested in a kg of contained U-235 at a typical LWR feed of 4.4% U-235. Compared with the 151 SWU[3] required to produce such fuel containing 1 kg of U-235, only 68 SWU need be added to yield 0.95 kg of 90% U-235.

The need for uranium feed to power indefinitely a greatly expanded nuclear power system leads to the consideration of reprocessing and even of breeding of nuclear fuel, which inherently on a large scale would require the treatment of spent fuel. For instance, each GWe-class LWR fissions about one ton of heavy metal per year and typically requires 200 tons of natural uranium per year to supply the U-235 that (together with some fraction of the plutonium fissioned in situ) contributes to the nuclear heat. An expansion from the current system of some 300 GW-e capacity to

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[2] "Management and Disposition of Excess Weapons Plutonium," a publication of the Committee on International Security and Arms Control, National Academy Press (1994). Available at http://www.nap.edu/catalog.php?record_id=2345.

[3] http://www.fas.org/rlg/SWU_Calculations_version_3_1.xls

9000 GW-e capacity would thus require the supply of 1.8 million tons of U per year, which might be considered reasonable if one takes the view that there are 250 million tons of uranium economically available in terrestrial resources. Reprocessing and recycle of Pu in LWRs can reduce the uranium need by no more than 20% and has clearly been uneconomical even where technically successful, as practiced in France; it has been a policy and financial failure where done with less competence, as in the United Kingdom

Uranium from seawater, where it is present to the extent of 3 parts per billion (ppb), to the total extent of some 4000 million tons of uranium, would clearly allow LWRs to supply much of the world's energy needs for ten centuries. The United States should expand its DOE program to understand and to reduce the cost of seawater uranium, in order to provide the option of an assured fuel supply and to limit costlier approaches such as, at present, the recycle of LWR fuel.

Ultimately a fast-neutron breeder reactor may, with sufficient development of analysis and simulation, be devised and demonstrated to be competitive with LWRs, and a combined reactor and fuel cycle simulation, with full treatment of safety and security implications, could lead to a viable approach to a breeder. I have long advocated a World Breeder Reactor Laboratory, for collaborative work on such an approach. In the meantime, over the past two years TerraPower has used relatively advanced simulation approaches on a so-called "Traveling Wave Reactor" that in its current incarnation resembles a conventional fast breeder reactor with the U-238/Pu-239 cycle[4].

This reactor might, in principle, consume about 15% of the U-238 fed to it before requiring reprocessing and recycle of the fuel, and the reprocessing would have little in common with the PUREX process, since the main function is to remove the accumulated fission products, to allow the density of the metal fuel to be retained against the growth of the fission product elements of considerably larger atomic volume per unit mass.

What influence can the Blue Ribbon Commission and the United States more generally have on proliferation?

The United States is not at present a leader in building of reactors or nuclear power installations worldwide, and it is unrealistic to imagine that it will be able to gain such market share that its approach will hold sway.

However, cogent analysis and diligent work in international fora of the United Nations and the IAEA could help to establish standards such as the "Stored Nuclear Weapon Standard" or "Spent Fuel Standard" for weapon-usable material and reprocessing, respectively, that could substantially ease the requirements to guard and protect the back end of the fuel cycle.

The main point, though, is that even a proliferation-proof nuclear power sector for the future must deal with the vast proliferation potential of the 400+ existing nuclear reactors and their spent fuel. This will not just fade away, and priority and funds to properly protect and sequester this material will be difficult to obtain, requiring the utmost in leadership. The magnitude of the problem, again, is set by the scale of the plutonium resource

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[4] "Traveling-Wave Reactors: A Truly Sustainable and Full-Scale Resource for Global Energy Needs," by Tyler Ellis, et al, Proceedings of ICAPP '10, June 13-17, 2010, Paper 10189.

present in the spent fuel—on the order of 6000 nuclear weapons per year of spent fuel in the world to the current system, multiplied by some 20 years average production, or 120,000 potential nuclear weapons. Since even 100 nuclear weapons constitutes a very substantial national armory and a potent force for disruption and destruction of the world system in the hands of terrorists, every reactor's spent fuel is a potential threat, and, especially, the separated reprocessed plutonium is an urgent threat to the entire world. Note that "co-processing" (in which plutonium is not obtained pure but typically mixed with an equal amount of uranium) poses no significant additional barrier. A nuclear future with 9000 reactors worldwide would produce spent fuel containing the equivalent of 200,000 weapons annually.

The goal of bringing the world's supply of weapon-usable material under control within four years is laudable, but priority and resources need to be applied to it. In addition to the risks of non-state acquisition of nuclear weapons, attention must be paid to protection of nuclear power and fuel cycle facilities against sabotage.