Physics and Society (July 2004)

PUREX AND PYRO ARE NOT THE SAME

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INTRODUCTION

In the early days of civilian nuclear power, it was assumed that PUREX -- an aqueous reprocessing method that was used in weapons programs to produce plutonium of the chemical purity needed for bombs -- would be suitable for recycling the fuel. The countries that had the most advanced civilian nuclear power programs already had PUREX plants to service their nuclear weapons programs.

In 1970, as nuclear technology and civilian nuclear power plants were beginning to spread to additional countries, the Nuclear Non-proliferation Treaty was put in place. Skepticism remained, however, as to whether that treaty was adequate to stem the increasing availability of separated plutonium. So in 1977, attempting to limit the availability of separated plutonium and the associated potential for proliferation of nuclear weapons, the Carter administration accepted the recommendation of the preceding Ford administration, and banned the reprocessing of commercial reactor fuel.

At that time, “reprocessing” meant PUREX. PUREX works well for thermal-reactor fuel, but it is not well suited for a fast-reactor fuel cycle, and it is very expensive. Consequently, a “dry” (nonaqueous) pyrometallurgical method was developed -- a process that cannot by itself produce plutonium of weapons-quality purity. With pyrometallurgical processing it's a new ball game.

Fast reactors have advantages in addition to a proliferation-resistant fuel cycle. They can consume plutonium and other long-lived actinides, reducing to less than 500 years the required isolation time for waste in a repository, postponing indefinitely the need for more repositories. They can get more than 100 times as much energy from uranium as the profligate once-through fuel cycle, and more than 50 times as much as thermal reactors with aqueous recycle.

.The Union of Concerned Scientists, an eminent public-interest group, has issued the following statement: "*UCS calls upon the Bush administration to pull the plug on reprocessing and encourage U.S. allies to do the same.*" However, advances in fast-reactor technology have made it inappropriate to use the word "reprocessing" generically, as though fuel cycles based on PUREX and pyroprocessing have equivalent proliferation potential. They don't. Continuing to prohibit recycling in the United States only aggravates the disposal problem and encourages the profligate waste of uranium resources. We therefore suggest that, to be consistent with its goals and values, UCS should modify its position to the following:

"***UCS calls on the Bush administration to pull the plug on aqueous reprocessing and encourage U.S. allies to do the same. Further, UCS also calls for initiating deployment of proliferation-resistant fast reactors, since they can consume virtually 100 percent of the low-quality plutonium produced by thermal reactors, along with the high-quality plutonium from weapons.***"

DISCUSSION

We all agree that the threat of nuclear terrorism is a matter of serious national and international concern. Today, any group with sufficient resources, along with access to current technology and to readily available materials, can make any of a variety of nuclear terrorist devices. There is also a wide range of terrorist threats involving WMD that are far more credible than nuclear terrorism. (We use the term "WMD" in its popular, all-inclusive sense, realizing nevertheless that the only true weapons of mass destruction are atomic bombs -- the others, including radiological weapons, being more properly characterized as "weapons of mass terror.")

The relevant question is this: *Is technology available that can reduce the threat of nuclearterrorism, or that can improve our energy posture or environment, without increasing the threat of nuclear terrorism or of nuclear-weapons proliferation?*

Note that this question is posed as a comparison, not an absolute. Any claim that a particular technology can guarantee that there will be no future nuclear terrorism threat or no potential for proliferation of nuclear weapons to more countries is either disingenuous or terribly naive.

A well-conceived program of nuclear recycle can reduce the threat of nuclear terrorism without significantly affecting the potential for nuclear proliferation. It can greatly improve our energy independence, and drastically reduce the environmental challenges involved in energy production. The most notable benefit is in waste management: only the true waste will be left, whose activity will be below background in less than 500 years.

It is important to realize that the nuclear fuel cycle can be "closed" (essentially all of the energy in the mined uranium exploited) *only* by consuming the actinides (uranium and transuranics) in a fast neutron spectrum.

Part I: Proliferation and Terrorism

Let's consider whether closing the nuclear fuel cycle by means of an advanced recycle technology such as pyrometallurgical recycle combined with fast reactors would properly addresses the above comparative question. Safety and economics are also relevant, but are not discussed here.

Nuclear terrorism could involve dirty bombs or even nuclear weapons. Presumably they would be rather basic devices, unless the terrorists got more sophisticated weapons from a new or established nuclear- weapons state. Each possibility should be considered.

Dirty Bombs. To many, dirty bombs are the most likely nuclear terrorist threat, even though they can do little physical damage. A dirty bomb could trigger panic, and could cause significant economic disruption due to the need to clean up the resultant contamination. To the extent that large-scale recycle would affect this threat, it would reduce it. Spent nuclear fuel would have economic value (perhaps minimal, at first)[1], which would provide the basis for improved accounting for spent fuels. Today, such accounting is unreliable, even worse than the world-wide accounting of more sensitive nuclear materials. Very significant is the fact that fast-reactor recycle would, in the long run, dramatically reduce the stores of old spent fuel, which, although only mildly self-protecting, would still be disruptive if used in a dirty bomb.

Terrorist Atomic Bombs. For a terrorist trying to construct a basic nuclear bomb, one of the main challenges is to acquire the weapons-grade uranium or plutonium. Enriched uranium is a serious concern because of the availability of centrifuge technology, even if the potential for subnational groups to use this technology is remote. Recycle (other than for consumption of excess weapons quality uranium) is irrelevant for a uranium-based device.

The prospect of a terrorist group constructing a plutonium-based bomb is even more remote, because of the task's complexity. Nevertheless the possibility cannot be ignored. As Carson Mark points out, use of a poor grade of plutonium could well result in a "fizzle," but even this would be an effective terrorist weapon. Consequently the stewardship of nuclear materials in general, including recycle activity, must be subject to appropriate safeguards. This is discussed below.

A far more credible threat is that a nuclear-weapons state could provide a surrogate group with weapons. Here again recycle is irrelevant.

Proliferation at the Nation Level. Any nation that is determined to acquire nuclear weapons can and will do so, regardless of U.S. recycle policy. What the U.S. can and must do is promote an international environment that reduces the incentive to proliferate and enforces international safeguards.

Part II: Safeguards Against Nuclear Terrorism

Safeguards involve physical protection, technical steps, and information control, including intelligence measures. This discussion is limited to technical matters. It is perhaps legitimate to ask whether the technical aspects of various recycle technologies should be classified, but that is beyond the scope of this discussion (anyway, it may already be too late).

The current IAEA approach to controlling nuclear terrorism is inadequate. The system is based on international verification of the signatory states' compliance and rigid commitments of intent.

There are vast quantities of weapons-usable materials spread around the world, and in some cases these materials are under very lax controls. Even obtaining estimates of the quantities of such materials, let alone their location and security, is almost impossible. The most credible nuclear terrorist threat, a dirty bomb, requires only access to spent nuclear fuel, and the controls on this material in various parts of the world are minimal. Thus we are seriously dependent on additional information from intelligence and surveillance.

The advanced separation technologies that have been studied and shown to be feasible present a minimal increase in risk. Such technologies constitute a considerably smaller proliferation or terrorism threat than the centrifuge. While they could be used by a well-funded and well-protected terrorist organization in doing part of the separation of plutonium from spent fuel, the facilities required for such a separation would be complex. The terrorists or proliferators would need, for example, to have a reasonably well shielded facility with remote manipulators (depending on how willing the operators were to accept high radiation doses).

They also would need a staff with expertise in chemical separations. To produce weapons-usable materials, the facility would have to have equipment for complex chemical separations that would not be present in a recycle application, whether it contained an aqueous separations unit or not. Even if the recycle system included an aqueous unit for the initial separation, the operating parameters for extracting weapons-useable plutonium would have to be significantly different, and therefore detectable under a suitable verification regime.

Because of the evident differences between using an elecrtorefining facility for recycle and using it for extracting materials for a weapons program, the technology would be susceptible to rigorous monitoring (although the monitoring method has not yet been adequately demonstrated).

For a plutonium-based weapon, possession of the fissile material is far from the only prerequisite: the device's design and construction are extremely demanding, and the ancillary equipment is critical.

Advanced technologies should be deployed under the most rigorous safeguards, and appropriate monitoring technologies should be an integral part of the development. There should be some form of physical control over the verification process, which should not be subject to veto by the inspected party. Planned and controlled deployment of nuclear power in the United States (under conditions that need to be developed) is far preferable to waiting for others to develop such technologies. In promoting the establishment of such a system, the Union of Concerned Scientists could play an important catalytic role.

Part III: A Bit of History and the Current Situation

The peaceful use of nuclear power has moved forward in major and somewhat disjointed steps, driven by clearly identifiable events or situations. The development of civilian nuclear power was initiated by President Eisenhower's Atoms for Peace program. The large-scale deployment in the United States was largely driven by economics, in response to the almost total dependence on coal as our basic energy resource, and the effective monopoly control over supplies of coal by John L. Lewis and the United Mine Workers. Nuclear power, supplemented by a modest contribution from domestic oil, broke the coal monopoly in the United States.

At about the same time, the Suez Canal crisis deprived England of its supply of oil, leaving it also totally dependent on coal and on the miners, who sought to exploit the situation to improve their economic condition. Nuclear energy provided the bridge until super-tankers made the Suez bottleneck irrelevant, and North Sea gas gave the U.K. an additional option. Similarly, France's nuclear power program, which today is a major factor in its economic well being, was undertaken in response to its loss of control over Algeria and its oil.

In today's economy, energy is used primarily for transportation, space heating, electricity, and industrial processes. In the United States, transportation is almost totally dependent on oil; heating is done largely by natural gas (along with some oil and coal); and electricity comes mainly from burning coal, with contributions from nuclear power (~20%), natural gas (~18%), and rivers and miscellaneous (including oil) (~11%). Industry is powered by all of the above.

With the notable exception of land and air transportation, virtually all energy demands could be satisfied with non-fossil sources, with electricity as the main means of delivery. That includes ocean transport, for which well-managed nuclear power is ideally suited, as the U.S. navy has amply demonstrated. Pending break-throughs in battery technology or in the generation and management of hydrogen, land and air transportation will continue to depend mainly on oil. But in the longer term, given the needed technology, even there nuclear power can help change our dependence on a near-monopoly energy source that we do not control. Removing this issue, and the gluttonous demands of the U.S. economy for imported oil, would reduce both the motivations for terrorism, and the resources to support it.

Much of the recently installed electric generating capacity in the United States is powered by natural gas, driving the price skyward. Since natural gas will for some time be used for heating (it makes cities far more healthful than they used to be), it is foolish to use this resource to produce electricity. The choice for electricity in the future comes down to nuclear or coal, and even with the most advanced technologies, coal is and will remain far more environmentally harmful than nuclear power.

Part IV: Other Benefits of Closing the Fuel Cycle

With fast-reactor recycle there will be better accounting for, and ultimately a reduction in, inventories of spent nuclear fuel; there will be a rethinking of technical safeguards approaches; and there will be a much greater incentive to have rigorous accounting of all nuclear materials.

There will be dramatic reductions in the toxicity of wastes to be disposed of. Best current estimates are that fast-reactor recycle will reduce net long term toxicity by something like two orders of magnitude. The final wastes can easily be tailored to an appropriate form for optimum security: long-lived isotopes in a metallic waste form (which can be highly corrosion resistant in the repository), shorter lived materials in ceramic waste forms. Radioactivity in a repository will reach background levels in less than 500 years.

With recycle integrated within a power generation complex, there will be a substantial reduction in transportation of nuclear fuel, both fresh and spent, with a concomitant reduction in opportunities for theft and sabotage.

There will be no need for uranium mining or milling for the foreseeable future. No enrichment needed, ever. (Possession of a plant for isotopic separation, centrifuge or otherwise, would be *ipso facto* evidence of intention to proliferate.) Residues of depleted uranium from previous weapons programs become valuable resources, not waste that is difficult to handle and dispose of.

Increased use of nuclear power will significantly reduce the atmospheric emissions associated with power generation, reducing both air pollution and greenhouse gases.

Part V: Electrochemical Separation Technologies

The advanced recycle technology that is closest to commercialization uses electrochemical methods. Both Argonne National Laboratory in this country, and Dmitrovgrad in Russia, have considerable experience, and have demonstrated the technical feasibility of separating heavy metals from highly enriched (fast reactor) fuels.[2][3]

These techniques are effective in separating the heavy metals in fast reactor spent fuel from the bulk of the fission products -- most notably, the cesium and strontium. This offers considerably increased flexibility in designing waste forms that are tailored to the hazards posed by the wastes. The recovered heavy metals are well suited for recycle into a fast reactor, either for consumption or for regeneration (breeding).

With further processing, such materials could also be used in a dirty bomb. In principle, they could even be used to construct a crude nuclear bomb, but the technology for this is surely beyond all but the most competent designers and technicians. Carson Mark has pointed out a few of the complexities of such an undertaking. Since terrorists cannot be counted upon to be realistic, this threat, however remote, is justification for rigid safeguards on electrochemical separation facilities.

Part VI: Weapons Usable?

Since the matter comes up over and over again, we now consider the weapons usefulness of reactor grade plutonium.

In policy circles, one of the great fears about nuclear power is its supposed connection to the spread of nuclear weapons. The usual statement is that "all plutonium is weapons usable," encouraging the inference that all plutonium is equally dangerous as a material for making nuclear weapons, which is incorrect.

While it is possible, using very sophisticated nuclear weapon designs, to get an explosive yield from reactor-grade plutonium, no country seeking nuclear weapons would use such material. As mentioned above, it is extremely difficult to design a weapon with reactor-grade plutonium. One problem, for example, is that so much heat is generated by that plutonium that when it is surrounded with high explosive to make a bomb, the explosive will decompose unless the assembly is equipped with very elaborate heat-removal features. Unsophisticated designers would not succeed. Furthermore, even with such problems solved, weapons made from reactor-grade plutonium have a yield that is highly unpredictable -- they would be very likely to “fizzle,” producing no mushroom cloud at all. Thus their usefulness as a military weapon is questionable to say the least, and even as a terrorist weapon that will definitely fizzle, they are technically beyond the reach of subnational terrorist organizations.

To our knowledge, a test carried out by the United States in 1962 is the only one ever performed that incorporated reactor grade plutonium. Unfortunately the details of that test are still classified. We are not told, for example, what fraction of the bomb’s fissile content was “reactor grade,” nor are we told the isotopic composition of the “reactor grade plutonium,” nor the fabrication complexities.

The government has stated only that the yield was less than 20 kilotons. It could have been very much less. This information is almost useless, since neither the actual yield nor the yield to be expected with high-quality plutonium has been revealed. Without at least the ratio of those two quantities, one cannot determine the degradation in yield due to using reactor grade plutonium rather than weapons grade. Furthermore, the importance of heat generation in the assembly tested is unknown, but probably it was finessed in some way rather than handled as would be necessary in a real-life weapon that used only reactor grade plutonium.

In short, we are denied the information that would let one evaluate the practical difficulties.

In his 1993 paper, J. Carson Mark wrote: “The difficulties of developing an effective design of the most straightforward type are not appreciably greater with reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium.”[4] That was based on his calculations, and on his apparent opinion that the heat problem is trivial. However, to our knowledge no weapons program, anywhere, ever, has made another attempt to produce an explosion with reactor-grade plutonium. It is extremely likely that the 1962 test demonstrated that reactor grade plutonium is lousy material for making bombs, and that no nation, given the data from that test, would want to use the stuff.

While the difference in weapons potential is one of degree rather than principle, that difference is huge. The point is not that it can’t be done, but rather that a would-be proliferator has far easier routes to nuclear weapons.

All reactors and all plutonium should be safeguarded, but reactor-grade material will be used only when all routes to higher fissile quality (uranium or plutonium) are cut off.

By the way, it has sometimes been asserted that the chemically impure plutonium produced by the pyrometallurgical process could be used to make a bomb without further separation. This has been convincingly refuted in an unpublished investigation by Livermore National Laboratory (1994),which concluded that the transuranic impurities render the material far too hot (thermally and radioactively), and with far too many spontaneous neutrons, to make it at all feasible.

Anyway, it is very much easier to make a bomb with highly enriched uranium than with reactor grade plutonium. That route would surely be taken by any organization that did not have access to weapons-grade plutonium.

CONCLUSIONS

No technology that involves the handling of nuclear materials, including the current once-through fuel cycle, can be totally immune to misuse. Regarding the current and short-term threat of nuclear terrorism, the status quo is not optimum. Relying solely on the current IAEA verification approach is adequate for controlling neither the inventory of nuclear materials nor any of the recycle technologies, current or advanced. Rigorous safeguards, including monitoring, surveillance, and accountancy, are necessary. The advanced recycle technologies offer no net additional potential for terrorist or proliferator, and appear to be adaptable to rigorous safeguards.

Since before the invention of fire, a new technology has always meant new risks. The genie, to be trite, cannot be put back in the bottle. In each case, society has learned to live with the risks in order to realize the benefits. All things considered, recycle of spent nuclear fuel to fast reactors will make a minimal contribution to the short-term risk of terrorism, provided that appropriate safeguards are instituted as an integral part of the process. In the longer term, recycle will significantly reduce the terrorist threat. Surely there can be no greater contribution to our national security than to lessen the tensions inherent in the world's massive dependence on oil.

Inevitably, nuclear power will supply a growing fraction of the growing global energy requirements. Although currently there is no shortage of uranium, continuing the profligate practice of treating spent fuel from thermal reactors as waste -- throwing away more than 98 percent of the energy in the mined uranium -- will swamp the waste-disposal facilities and exhaust the reserves of low-cost uranium. Fast reactors can run happily on that "waste," meeting the growing energy demand for decades before any more mining or milling of uranium is needed -- and enrichment will never be needed. The basic technology is now in hand.

Those who would restrict the growth of nuclear power in the United States would deprive it of the ability to help set the guidelines and structure within which the spread occurs -- an important recent example being the sale of Chinese reactors to Pakistan. We hope that UCS will decide to be part of the solution, rather than part of the problem.

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[1] Ehrman et al. have calculated that LWR spent fuel could be processed to supply LMRs at no cost to the government -- the cost being covered by the (competitive) busbar cost of power from the LMRs. [C. S. Ehrman et al,"Design Considerations for a Pyroprocess Recycle Facility," Global '95 Fuel Cycle Conference, Versailles, France,September 11-14, 1995]

[2] *Progress in Nuclear Energy*, Vol 31, Number 1,2, 1997, *The Technology of the Integrated Fast Reactor and its Associated Fuel Cycle.*

[3] Bychkov, A. V., S. K. Vavilov, P. T. Porodnov and O. V. Skiba (1993). Pyroelectrochemical Reprocessing ofIrradiated Uranium-Plutonium Oxide Fuel for Fast Reactors. *Proceedings of the International Conference on FutureNuclear Systems: Emerging Fuel Cycles and Waste Disposal Options, p. 1351, Seattle, WA, 12-17 September*

[4] J. Carson Mark, “Explosive Properties of Reactor-Grade Plutonium.” *Science and Global Security*, Volume 4,pp.11l-128 (1993). <http://www.princeton.edu/%7Eglobsec/publications/pdf/4_1Mark.pdf>