

ASSESSING THE BENEFITS, COSTS, AND RISKS OF NEAR-TERM REPROCESSING AND ALTERNATIVES

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ABSTRACT

Policies for management of spent nuclear fuel should focus on those options that offer the best combination of low cost, low proliferation risks, low environmental impact, high safety and security, and high sustainability. Traditional PUREX reprocessing technologies are inferior to once-through approaches in most of these respects. Proposed new separations and transmutations approaches such as UREX+ and pyroprocessing are at an early stage of development, and moving quickly toward selecting particular technologies, carrying out engineering-scale demonstrations, and building commercial-scale facilities risks locking in to poor choices, repeating past mistakes. The higher cost of reprocessing and recycling, while small per kilowatt-hour, will amount to an additional tens of billions of dollars in the cost of managing U.S. spent nuclear fuel, which would have to come either from government subsidies lasting many decades (which might not be sustained), a major increase in the nuclear waste fee, or regulations that would effectively force private industry to build and operate uneconomic facilities; all of these options would cast additional doubt on private investments in new nuclear plants in the United States. Dry cask storage provides a safe, proven, low-cost approach to spent fuel management for decades, leaving all options open and making it possible to make better-informed decisions when technology has advanced and economic and political circumstances have evolved. The laudable goals of the Global Nuclear Energy Partnership can be achieved without reprocessing and recycling. Indeed, the future of nuclear energy will be best promoted by making nuclear energy as safe, cheap, proliferation-resistant, and uncontroversial as possible, and recycling using the technologies available today or likely to be available in the near term points in the wrong direction on each of those counts.

INTRODUCTION

The proposed Global Nuclear Energy Partnership (GNEP), announced in February 2006, is a broad initiative to promote the growth of nuclear energy worldwide.¹ Unfortunately, while several elements of the initiative are important and worthwhile, the heavy focus on reprocessing and recycling is more likely to undermine than to enhance the future of nuclear energy.

Recycling is not an end in itself, whether for newspapers or for spent fuel. Rather, it is a way to conserve scarce resources and reduce disposal costs. If all the real costs and externalities are appropriately reflected in prices, and recycling costs more than direct disposal, that means that recycling is wasting more precious resources than it is conserving: the capital and labor invested in recycling, in that case, are more precious than the resources conserved by doing so. When old computers are discarded, the precious metals in them are often recycled, but the silicon in their chips is generally not: silicon is plentiful, recovering and recycling it would be expensive, and disposal of it is not a major problem. It is worth at least considering whether or not the same is true in the case of recycling spent nuclear fuel.

In the case of spent fuel, management policies should be chosen that offer the best combination of low cost, low proliferation risks, low environmental impact, high safety and security, and high sustainability for a growing long-term nuclear enterprise. Reprocessing using either traditional PUREX technology or the UREX+ technology proposed for GNEP is inferior to once-through approaches in most of these respects. But there is no need to rush in either direction: spent fuel can be stored safely and cheaply for decades in dry casks, leaving all options open for the future, and allowing time for the economic, technical, and political issues on all paths to be more fully explored..

COSTS AND FINANCING

Reprocessing and recycling using current or near-term technologies would substantially increase the cost of nuclear waste management, even if the cost of both uranium and geologic repositories increase significantly. In a recent Harvard study, we concluded, even making a number of assumptions that were quite favorable to reprocessing, that shifting to reprocessing and recycling would increase the costs of spent fuel management by more than 80% (after taking account of appropriate credits or charges for recovered plutonium and uranium from reprocessing).² Reprocessing (at an optimistic reprocessing price) would not become economic until uranium reached a price of over \$360 per kilogram – a price not likely to be seen for many decades, if then.

Government studies even in countries such as France and Japan have reached similar conclusions.³ The UREX+ technology now being pursued adds a number of complex separation steps to the traditional PUREX process, in order to separate important radioactive isotopes for storage or transmutation,⁴ and there is little doubt that reprocessing and transmutation using this process would be even more expensive. Other processes might someday reduce the costs, but this remains to be demonstrated, and a number of recent official studies have estimated costs for reprocessing and transmutation that are far *higher* than the costs of traditional reprocessing and recycling, not lower.⁵ A National Academy of Sciences review of separations and transmutation technologies such as those proposed for GNEP concluded that the additional cost of recycling compared to once through for 62,000 tons of commercial spent fuel “is likely to be no less than \$50 billion and easily could be over \$100 billion.”⁶

While this would be a modest addition to total per-kilowatt-hour costs of nuclear electricity generation, the absolute magnitude of the amount is large, and there are only a few ways it could be financed: either (1) the current 1 mill/kilowatt-hour nuclear waste fee would have to be substantially increased; (2) the federal government would have to provide tens of billions of dollars of subsidies over many decades (which might not be sustained), or (3) onerous regulations would have to be imposed that would effectively require private industry to build and operate uneconomic facilities. All of these options would make investors more uncertain about putting their money into new nuclear plants in the United States. Most approaches would represent dramatic government intrusions into the private nuclear fuel industry, whose implications have not been fully examined.

PROLIFERATION RISKS

The reprocessing proposed as a central part of GNEP raises troubling proliferation issues, of several kinds.

First, there is the proposal’s potential impact on the spread of reprocessing to additional countries that might apply the technology to their nuclear weapons programs – a spread the United States has been attempting to limit for more than three decades, and whose importance President Bush has emphasized.⁷ Since 1976, the U.S. message has been, in effect, “reprocessing is unnecessary; we, the country with the world’s largest nuclear fleet, are not doing it, and you do not need to either.” Now, with GNEP, the message is “reprocessing is essential to the future of nuclear energy, but we will keep the technology away from all but a few states.”⁸ This is not likely to be an acceptable and sustainable approach for the long haul. In particular, this message is likely to make it more difficult, not less, to convince states such as Taiwan and South Korea – both of which have had secret nuclear weapons programs based on reprocessing in the past, terminated under U.S. pressure – not to pursue reprocessing of their own. Having other countries pursue UREX+ rather than PUREX would not be much of an improvement, as a facility implementing UREX+ could be adapted very rapidly to separate pure plutonium for weapons.

GNEP advocates argue, to the contrary, that another central element of GNEP – the idea of a consortium of fuel cycle states that would provide fuel to other countries and manage their spent fuel as well – would reduce the incentives for states to acquire reprocessing facilities (as well as enrichment facilities) of their own. This is an important and potentially powerful idea, which should be pursued.⁹ Unfortunately, the way a few GNEP advocates have presented the idea, focusing on a new regime of discrimination and denial in which all but a few states would be denied access to enrichment and reprocessing technology, is unlikely to make the concept popular among the potential recipients of such fuel leases. A substantively similar but

more appealing approach is to say that, in effect, countries will be offered *more* than they have ever been offered before under Article IV of the Nonproliferation Treaty: a guarantee of life-cycle fuel supply and spent fuel management for as many reactors as they choose to build, if they agree that, at least for an agreed period, they will not pursue enrichment and reprocessing facilities of their own.

In any case, U.S. reprocessing is not an essential part of making such an offer. A U.S. offer to take in unlimited quantities of foreign spent nuclear fuel is simply not politically realistic – even if the spent fuel was to be reprocessed after it arrived. (Indeed, few steps would be more likely to destroy renewed public support for nuclear energy in the United States than proposing to make the United States “the world’s nuclear dumping ground,” as anti-nuclear activists have put it in the case of Russia.) Realistically, if major states are to make such a back-end offer, it will be others who do so – starting with Russia, which has already put in place legislation to make that possible. Russia currently plans to offer such fuel leases and to put imported spent fuel in secure dry storage for decades, though at present it does plan to reprocess it eventually.

A second set of proliferation issues focuses on possible theft or diversion of plutonium. While reactor-grade plutonium would not be the preferred material for making nuclear bombs, it does not require advanced technology to make a bomb from reactor-grade plutonium: any state or group that could make a bomb from weapon-grade plutonium could make a bomb from reactor-grade plutonium.¹⁰ Despite the remarkable progress of safeguards and security technology over the last few decades, processing, fabricating, and transporting tons of weapons-usable separated plutonium every year – when even a few kilograms is enough for a bomb – inevitably raises greater risks than not doing so. Indeed, while many of the stocks of civil plutonium that have built up are well-guarded, critics have argued that some operations in the civilian plutonium industry are potentially vulnerable to nuclear theft.¹¹

The administration has acknowledged that the huge stockpiles of weapons-usable separated civil plutonium built up as a result of traditional PUREX reprocessing (now roughly equal to all world military plutonium stockpiles combined, remarkably) “pose a growing proliferation risk” that “simply must be dealt with”¹² – a characterization but seems oddly out of tune with the schedule of the administration’s proposed solution, advanced burner reactors that will not be available in significant numbers to address this “growing” risk for decades. In a similar vein, the British Royal Society, in a 1998 report, warned that even in an advanced industrial state like the United Kingdom, the possibility that plutonium stocks might be “accessed for illicit weapons production is of extreme concern.”¹³

Advocates argue that the more advanced approaches now being pursued would be more proliferation-resistant, because the minor actinides (and perhaps a few of the lanthanide fission products) would remain with the plutonium, making the separated product more radioactive and more problematic to steal and process into a bomb. Of all the various impacts of civilian nuclear energy on proliferation, this would *only* help with respect to the difficulty of theft of the separated material and processing it into a bomb: while that is not unimportant, there has never yet been an historical case in which this was the key in determining the civilian nuclear system’s impact on proliferation outcomes.¹⁴ Moreover, the processing proposed in UREX+ still takes away the great mass of the uranium and the vast majority of the radiation from the fission products, making the process far less proliferation-resistant than simply leaving the plutonium in the spent fuel. Indeed, the plutonium-bearing materials that would be separated in either the UREX+ process or by pyroprocessing would not be radioactive enough to meet international standards for being “self-protecting” against possible theft.¹⁵ Thus, the approach may be considered modestly more proliferation-resistant than traditional PUREX reprocessing, but it is far less proliferation-resistant than not reprocessing at all.

Proponents of reprocessing and recycling often argue that this approach will provide a nonproliferation benefit, by consuming the plutonium in spent fuel, which would otherwise turn geologic repositories into potential plutonium mines many hundreds or thousands of years in the future. But the proliferation risk posed by spent fuel buried in a safeguarded repository is already modest; if the world could be brought to a state in which such repositories were the most significant remaining proliferation risk, that would be cause for great celebration. Moreover, this risk will be occurring a century or more from now, and if there is one thing we know about the nuclear world a century hence, it is that we know almost nothing

about it. We should not increase significant proliferation risks in the near term in order to reduce already small and highly uncertain proliferation risks in the distant future.¹⁶

With crises brewing over the nuclear programs of North Korea and Iran, and a variety of targets for nuclear theft that are more vulnerable than most of the proposed recycling operations in GNEP would be likely to be (such as HEU-fueled research reactors in many countries, for example), the issues raised by GNEP are not among the world's highest proliferation risks. But they are real risks nonetheless, and running them is entirely unnecessary, given the availability of dry cask storage as a secure alternative.

SAFETY AND SECURITY

Reprocessing and recycling using technologies available in the near term would be likely to raise additional safety and terrorism risks. Until Chernobyl, the world's worst nuclear accident had been the explosion at the reprocessing plant at Kyshtym in 1957, and significant accidents at both Russian and Japanese reprocessing plants occurred as recently as the 1990s. The British THORP plant remains shut following the 2005 discovery of a massive leak of radioactive acid solution containing tens of tons of uranium and some 160 kilograms of plutonium, which had gone unnoticed for months (though none of this material ever left the plant, and there was no known radioactive release). No complete life-cycle study of the safety and terrorism risks of reprocessing and recycling compared to those of direct disposal has yet been done by disinterested parties. But it seems clear that extensive processing of intensely radioactive spent fuel using volatile chemicals presents more opportunities for release of radionuclides than does leaving spent fuel untouched in thick metal or concrete casks.

ENVIRONMENTAL IMPACT

The question, then, is whether the benefits reprocessing and recycling would bring are large enough to justify accepting this daunting list of costs and risks.

Advocates argue that, with the advanced reprocessing and recycling proposed in GNEP: (1) there would be much less nuclear waste, most of the long-lived isotopes in spent fuel would be fissioned or transmuted, and hence the long-term environmental impact of geologic waste repositories would be reduced; (2) available uranium resources would be used much more efficiently, making nuclear energy more sustainable; and (3) with the actinides that generate most of the long-term heat from spent fuel removed, far more waste could be packed into a given area of a nuclear waste repository, possibly obviating the need for a second repository after Yucca Mountain.

Reprocessing and recycling as currently practiced (with only one round of recycling the plutonium as uranium-plutonium mixed oxide (MOX) fuel) does not have any of these benefits, to any substantial degree. The estimated long-term doses to humans and the environment from the repository are not noticeably reduced in such a fuel cycle. The amount of energy generated from each ton of uranium mined is increased by less than 20%.¹⁷ The size of a repository needed for a given amount of waste is determined not by the volume of the waste but by its heat output. Because of the build-up of heat-emitting higher actinides when plutonium is recycled, the total heat output of the waste per kilowatt-hour generated is actually higher – and therefore the needed repositories larger and more expensive – when disposing of HLW from reprocessing and spent MOX fuel after one round of recycling than it is for direct disposal.¹⁸

The approaches proposed in GNEP call instead for separating actinides and irradiating them repeatedly in advanced burner reactors, so that all but a small percentage of the actinides would be fissioned, and possibly some of the longer-lived fission products transmuted as well. These approaches might provide a substantial reduction in projected long-term radiological doses from a geologic repository, and, as discussed below, allow much more waste to be emplaced in a repository like Yucca Mountain.

But the projected long-term radioactive doses from a geologic repository are already low; hence the benefit of reducing them further is small. While the relevant studies have not yet been done, it seems very likely that if reducing environmental risks from the repository were the principal goal of recycling, the cost per life saved would be in the billions of dollars – and those possibly saved lives would be tens of thousands of years in the future. (Most of the discussions of these issues focus only on the high-level wastes, but the

substantial volumes of transuranic and low-level wastes generated in the course of reprocessing and of decommissioning the relevant facilities must also be considered.)

Moreover, the near-term environmental impacts of reprocessing and recycling (including fabrication, transport, and use of the proposed highly radioactive fuels), even when balanced in part by the reduction in the amount of uranium mining that would be required, are likely to overwhelm the possible long-term environmental benefit of reduced exposures from a geologic repository – though no credible study has yet been done comparing these risks for the proposed GNEP fuel cycle and once-through fuel cycles.

SUSTAINABILITY

Uranium Supply

Advocates argue that the recycling proposed in GNEP is essential because, with a growing nuclear energy enterprise in the future, a once-through approach would soon run short of either uranium or repository space. In neither case is the resource as limited as advocates claim.

Recycling and breeding can potentially dramatically extend uranium resources. But world resources of uranium likely to be economically recoverable in future decades at prices far below the price at which reprocessing and breeding would be economic are sufficient to fuel a growing global nuclear enterprise for many decades, relying on direct disposal without recycling.¹⁹ The current run-up in uranium prices has nothing to do with a lack of resources in the ground, but only with constraints on bringing on new production to exploit those resources to meet market demand. At a current price of over \$100/kgU, producers able to provide supply at costs of less than \$40/kgU are making immense profits; market players, seeing those profits, will attempt to bring additional supply on-line, ultimately bringing demand and supply into better balance and driving prices down. This will be difficult to do quickly, because of regulatory and political constraints in uranium-producing countries. But it would be surprising indeed if the price remained far above the cost of production for decades. Indeed, in the last decade, the “Red Book” estimates of world uranium resources have been increasing far faster than uranium has been consumed²⁰ – and that trend is likely to accelerate substantially now that high prices are leading to far larger investments in uranium exploration. The more we look, the more uranium we are likely to find.

Nor does reprocessing serve the goal of energy security, even for countries such as Japan, which have very limited domestic energy resources. If energy security means anything, it means that a country’s energy supplies will not be disrupted by events beyond that country’s control. Yet events completely out of the control of any individual country – such as a theft of poorly guarded plutonium on the other side of the world – could transform the politics of plutonium overnight and make major planned programs virtually impossible to carry out. Japan’s experience following the scandal over BNFL’s falsification of safety data on MOX fuel, and following the accidents at Monju and Tokai, all of which have delayed Japan’s plutonium programs by many years, makes this point clear. If anything, plutonium recycling is much *more* vulnerable to external events than reliance on once-through use of uranium.

Repository Space Supply

Some GNEP advocates argue not that uranium will run out, but that available space for nuclear waste in geologic repositories will run out. Spent nuclear fuel must be processed, and heat-generating radionuclides must be transmuted, they assert, to make it possible to pack the nuclear waste from the generation of a much larger amount of nuclear energy generation into planned repositories.²¹

If the proposed GNEP approach met all of its technical goals (none of which are demonstrated at present), it could indeed make it possible to dramatically expand the capacity of the proposed Yucca Mountain repository.²²

But repository space, like uranium, is a more plentiful resource than GNEP advocates have argued. Means to increase the quantity of spent fuel that can be emplaced in Yucca Mountain while remaining within thermal limits are only now being examined seriously, and the latest estimates indicate that the Yucca Mountain repository can almost certainly hold over 260,000 tons of spent fuel (an amount that would not exist until well into the latter half of the century even with rapid nuclear growth); it may well be able to hold 570,000 tons or more.²³

Moreover, whatever this argument's merits in the U.S. context, it only applies to the United States. Only the United States has chosen a repository site inside a mountain with fixed boundaries, whose capacity therefore cannot be increased indefinitely by simply digging more tunnels. Most other countries are examining sites in huge areas of rock, where the amount of waste from centuries of nuclear waste generation could be emplaced at a single site, if desired.²⁴ For this reason, measuring quantities of spent fuel in "Yucca Mountain equivalents" is highly misleading; if, in fact, a second repository is ever needed, it is unlikely that the nation will again make the mistake of choosing one that is not readily expandable.

The argument is based on the questionable assumption that while it would be very difficult to gain public acceptance and licensing approval for a second repository, it would *not* be very difficult to gain public and regulatory approval for the complex and expensive spent fuel processing and transmutation facilities needed to implement this approach – including scores of advanced burner reactors. This assumption appears very likely to be wrong. Reprocessing of spent fuel has been fiercely opposed by a substantial section of the interested public in the United States for decades—and the real risks to neighbors from a large above-ground reprocessing plant performing daily processing of spent fuel are inevitably larger than those from nuclear wastes sitting quietly deep underground. Similarly, there seems little doubt that licensing and building the new reactor types required would be an enormous institutional and political challenge.

The proposed GNEP approaches are an extremely expensive way to solve the problem, if there is one. The recent Harvard study concluded that if, as recent international reviews suggest, the more complex separations involved in a transmutation approach would be somewhat more expensive than traditional reprocessing, and fabrication of the intensely radioactive transmutation fuels would be somewhat more expensive than traditional MOX fabrication, and if the needed transmutation reactors or accelerators would have a capital cost roughly \$200/kW_e higher than that of comparably advanced one-through systems (a quite optimistic assumption, given past experience), then separations and transmutation for this purpose would not be economic until the cost of disposal of spent fuel reached some \$3000 per kilogram of heavy metal, many times its current level.²⁵

This argument is also based on a further questionable assumption—that even decades in the future, when repository space has become scarce and reactor operators become willing to pay a significant price for it, it will still not be possible to ship spent fuel from one country to another for disposal. (This is an odd assumption given GNEP's simultaneous emphasis on fuel leasing, involving countries shipping back spent fuel to the state that provided it.) If, in fact, repository capacity does become scarce in the future, reactor operators will likely be willing to pay a price for spent fuel disposal well above the cost of providing the service, and it seems quite likely that if the potential price gets high enough, the opportunity for enormous profit will motivate some country with an indefinitely-expandable repository to overcome the political obstacles that have blocked international storage and disposal of spent fuel in the past, and offer to accept spent fuel from other countries on a commercial basis. (It is worth noting that Russia has already passed legislation approving such imports of foreign spent fuel, though the prospects for implementation of that project remain uncertain.)²⁶

In short, once-through approaches will likely be able to provide sustainable uranium supply and repository space supply for a growing nuclear energy enterprise around the world for many decades or more, with costs and environmental impacts lower than or comparable to those of the proposed GNEP approaches.

TIMING: BOTH TOO SLOW AND TOO FAST

One of the remarkable aspects of the GNEP is its failure to address the U.S. nuclear industry's three immediate needs relating to management of spent nuclear fuel. These are (1) the need to manage spent fuel building up at existing reactor sites as a result of the U.S. government's failure to meet its obligation to begin taking it away in 1998; (2) the need to gain regulatory approval for construction and loading of a Yucca Mountain repository; and (3) the need to convince potential investors in new nuclear power plants that they will not be saddled with an indefinite liability for the spent fuel the plants generate. GNEP as currently conceived is too slow to have much benefit for any of these problems.

GNEP envisions an engineering-scale demonstration of the UREX+ technology beginning in 2011. This would be followed, presumably many years later, by the opening of a commercial-scale plant with a

capacity of over 2000 tons of heavy metal per year (tHM/yr).²⁷ While that is far larger than any current commercial reprocessing plant, it is only enough to address the spent fuel U.S. nuclear power plants generate each year – so it would do nothing to work off the backlog of tens of thousands of tons of spent fuel that will exist by the time the plant comes on line. Similarly, a demonstration “advanced burner reactor” is not expected to be operational until 2014, with a first commercial plant not expected until 2023.²⁸

It is clear from these schedules that GNEP as presently envisioned will not contribute anytime soon to addressing the problems posed by the build-up of spent fuel at reactor sites, or the growing government liability for its failure to meet its contractual obligations. Similarly, if Yucca Mountain is to be licensed any time in the next decade, it will have to be licensed without knowing whether GNEP will be workable and provide the kinds of reductions in the heat and radiotoxicity of wastes that are currently envisioned. As for investors in new power plants, a mere possibility that the government may complete development of new technologies for spent fuel long in the future does not solve their problem – and as noted above, proposals whose financing would require massive government subsidies of uncertain sustainability or large increases in costs to the private sector are likely to increase, not decrease, investors’ perception that spent fuel poses a large and uncertain liability.

While too slow to meet the industry’s immediate needs, these proposed schedules are far too fast to be realistic or to be a sensible approach to managing a long-term research and development (R&D) effort. The schedules seem to be driven more by impatience than analysis. DOE expects that it will not be able to open a MOX plant which is effectively a copy of existing European plants, using well-demonstrated technology, until 2015, although the design is nearly complete and the NRC has already authorized construction. Yet is simultaneously expects to be able to design from scratch, get approval for, and build a prototype ABR that will be operational one year earlier, which is absurd. Moreover, the proposed new separations and transmutations approaches are at a very early stage of development, and moving quickly toward selecting particular technologies, carrying out engineering-scale demonstrations, and building commercial-scale facilities risks locking in to poor choices (as has so often happened before in nuclear history). Despite the poor record of government choosing technological winners, DOE is already making this mistake: UREX+ and sodium-cooled fast reactors were chosen not because they are the only technologies that might prove attractive for the purpose, but because they were the only ones that might possibly be made available on the rushed schedule now being demanded. As Richard Garwin has put it, by picking winners prematurely, GNEP “would launch us into a costly program that would surely cost more to do the job less well than would a program at a more measured pace guided by a more open process.”²⁹

THE KEY ALTERNATIVE: INTERIM STORAGE

Fortunately, there is no need to rush to make this decision. Dry storage casks offer the possibility of storing spent fuel cheaply, safely, and securely for decades, while leaving all options open for the future. (Dry cask storage for 40 years would cost less than \$200/kgHM, compared to 5-10 times that cost for reprocessing.³⁰) During that time, technology will develop; interest will accumulate on fuel management funds set aside today, reducing the cost of whatever we choose to do in the long run; political and economic circumstances may change in ways that point clearly in one direction or the other; and the radioactivity of the spent fuel will decay, making it cheaper to process in the future, if need be. Indeed, as Yucca Mountain is expected to remain open, with the spent fuel fully retrievable, for 50-100 years or more, even emplacement of spent fuel in a geologic repository will keep all options open for decades to come, while maintaining the institutional momentum of the repository program, which will be essential for all options. Our generation has an obligation to set aside sufficient funds so that we are not passing unfunded obligations on to our children and grandchildren, but it is not our responsibility to make and implement decisions prematurely, thereby depriving future generations of what might turn out to be better options developed later.

To address the immediate needs of the U.S. nuclear industry, the U.S. government should be designing and implementing an interim storage plan that will allow it fulfill its obligation to take responsibility for, and pay the costs of, managing spent fuel. A variety of specific approaches have been proposed; it seems likely that the best approach would combine, to some degree, dry cask storage at existing reactor sites with centralized dry storage at one or several sites.

CONCLUSIONS AND RECOMMENDATIONS

For the reasons just outlined, I recommend that we follow the advice of the bipartisan National Commission on Energy Policy, which reflected a broad spectrum of opinion on energy matters generally and on nuclear energy in particular, and recommended that the United States should:

- (1) “continue indefinitely the U.S. moratoria on commercial reprocessing of spent nuclear fuel and construction of commercial breeder reactors”;
- (2) establish expanded interim spent fuel storage capacities “as a complement and interim back-up” to Yucca Mountain;
- (3) proceed “with all deliberate speed” toward licensing and operating a permanent geologic waste repository; and
- (4) continue research and development on advanced fuel cycle approaches that might improve nuclear waste management and uranium utilization, without the huge disadvantages of traditional approaches to reprocessing.³¹

At the same time, the U.S. government should redouble its efforts to: (a) limit the spread of reprocessing and enrichment technologies, as a critical element of a strengthened nonproliferation effort, including through the kind of assured fuel supply and spent fuel management offers envisioned in GNEP; (b) ensure that every nuclear warhead and every kilogram of separated plutonium and highly enriched uranium (HEU) worldwide are secure and accounted for, as the most critical step to prevent nuclear terrorism;³² and (c) convince other countries to end the accumulation of plutonium stockpiles, and work to reduce stockpiles of both plutonium and HEU around the world. Similar recommendations have been made in the MIT study on the future of nuclear energy,³³ and in the American Physical Society study of nuclear energy and nuclear weapons proliferation.³⁴

It remains possible that someday approaches to reprocessing and recycling will be developed that make security, economic, political, and environmental sense. Research and development should explore such possibilities. Continued investment in R&D on advanced fuel cycle technologies is justified, in part to ensure that the United States will have the technological expertise and credibility to play a leading role in limiting the proliferation risks of the fuel cycle around the world. But the leverage of these technologies in meeting the most serious energy challenges of the 21st century is likely to be somewhat limited in comparison to the promise of other potential future energy technologies, and the emphasis that nuclear fuel cycle R&D should receive in the overall energy R&D portfolio should reflect that.

The global nuclear energy system would have to grow substantially if nuclear energy was to make a substantial contribution to meeting the world’s 21st century needs for carbon-free energy. Building the support from governments, utilities, and publics needed to achieve that kind of growth will require making nuclear energy as cheap, as simple, as safe, as proliferation-resistant, and as terrorism-proof as possible. Reprocessing using any of the technologies likely to be available in the near term points in the wrong direction on every count.³⁵ Those who hope for a bright future for nuclear energy, therefore, should oppose near-term reprocessing of spent nuclear fuel.

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- ¹ For an official overview of GNEP, see the program’s web page, available as of 7 July 2006 at <http://www.gnep.gov>.
- ² See Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003, available as of 16 July 2006 at http://bcsia.ksg.harvard.edu/BCSIA_content/documents/repro-report.pdf). For quite similar conclusions, see John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: Massachusetts Institute of Technology, 2003, available as of 16 July 2006 at <http://web.mit.edu/nuclearpower/>).
- ³ See Jean-Michel Charpin, Benjamin Dessus, and René Pellat, *Economic Forecast Study of the Nuclear Power Option* (Paris, France: Office of the Prime Minister, July 2000, available as of December 16, 2003 at http://fire.pppl.gov/eu_fr_fission_plan.pdf), Appendix 1. In Japan, the official estimate is that reprocessing and

recycling will cost more than \$100 billion over the next several decades, and the utilities have successfully demanded that the government impose an additional charge on all electricity users to pay the extra costs.

⁴ George F. Vandegrift et al., "Designing and Demonstration of the UREX+ Process Using Spent Nuclear Fuel," paper presented at "ATALANTE 2004: Advances for Future Nuclear Fuel Cycles," Nimes, France, June 21-24, 2004, available as of 16 July 2006 at http://www.cmt.anl.gov/Science_and_Technology/Process_Chemistry/Publications/Atalante04.pdf.

⁵ See, for example, Organization for Economic Cooperation and Development, Nuclear Energy Agency, *Accelerator-Driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A Comparative Study* (Paris, France: NEA, 2002, available as of 16 July 2006 at <http://www.nea.fr/html/ndd/reports/2002/nea3109-ads.pdf>), p. 211 and p. 216; U.S. Department of Energy, Office of Nuclear Energy, *Generation IV Roadmap: Report of the Fuel Cycle Crosscut Group* (Washington, DC: DOE, 18 March 2001, available as of 16 July 2006 at <http://www.ne.doe.gov/reports/GenIVRoadmapFCCG.pdf>), p. A2-6 and p. A2-8.

⁶ U.S. National Research Council, Committee on Separations Technology and Transmutation Systems, *Nuclear Wastes: Technologies For Separation and Transmutation* (Washington, D.C.: National Academy Press, 1996), p. 7. Note that these figures are expressed in 1992 dollars; in 2006 dollars, the range would be \$66-\$133 billion.

⁷ President George W. Bush, "President Announces New Measures to Counter the Threat of WMD: Remarks by the President on Weapons of Mass Destruction Proliferation, Fort Lesley J. McNair - National Defense University" (Washington, D.C.: The White House, Office of the Press Secretary, 2004; available at <http://www.whitehouse.gov/news/releases/2004/02/20040211-4.html> as of 12 April 2005).

⁸ This formulation is adapted from Frank von Hippel, "GNEP and the U.S. Spent Fuel Problem," congressional staff briefing, 10 March 2006.

⁹ See, for example, John Deutch et al., "Making the World Safe for Nuclear Energy," *Survival* 46, no. 4 (Winter 2004; available at <http://www.world-nuclear.org/opinion/survival.pdf> as of 7 July 2006) and Ashton B. Carter and Stephen A. LaMontagne, "Toolbox: Containing the Nuclear Red Zone Threat," *The American Interest* (Spring 2006).

¹⁰ For an authoritative unclassified discussion, see *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-0007 (Washington DC: U.S. Department of Energy, January 1997), pp. 38-39.

¹¹ Ronald E. Timm, *Security Assessment Report for Plutonium Transport in France* (Paris: Greenpeace International, 2005; available at <http://greenpeace.datapps.com/stop-plutonium/en/TimmReportV5.pdf> as of 6 December 2005).

¹² Samuel Bodman, *Carnegie Endowment for International Peace Moscow Center: Remarks as Prepared for Secretary Bodman* (Moscow: U.S. Department of Energy, 2006; available at <http://energy.gov/news/3348.htm> as of 17 March 2006).

¹³ The Royal Society, *Management of Separated Plutonium* (London: Royal Society, 1998, available at <http://www.royalsoc.ac.uk/displaypagedoc.asp?id=18551> as of 16 July 2006).

¹⁴ For a discussion of broader issues that should be considered in assessing proliferation-resistance, and rough measures for assessing them, see Matthew Bunn, "Proliferation-Resistance (and Terror-Resistance) of Nuclear Energy Systems" in *Lecture, Massachusetts Institute of Technology* (Cambridge, Mass.: Project on Managing the Atom, Harvard University, 2006; available at http://bcsia.ksg.harvard.edu/BCSIA_content/documents/proliferation_resist_lecture06.pdf as of 7 July 2006).

¹⁵ See 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, pp. 169-181, 2005, available as of 16 July 2006 at http://www.princeton.edu/~globsec/publications/pdf/13_3%20Kang%20vonhippel.pdf

¹⁶ For a discussion, see John P. Holdren, "Nonproliferation Aspects of Geologic Repositories," presented at the "International Conference on Geologic Repositories," October 31-November 3, 1999, Denver, Colorado; available as of 16 July 2006 at http://bcsia.ksg.harvard.edu/publication.cfm?program=CORE&ctype=presentation&item_id=1.

¹⁷ John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: Massachusetts Institute of Technology, 2003, available as of June 9, 2005 at <http://web.mit.edu/nuclearpower/>), p. 123. They present this result as uranium consumption per kilowatt-hour being 15% less for the recycling case; equivalently, if uranium consumption is fixed, then electricity generation is 18% higher for the recycling case.

¹⁸ See, for example, Brian G. Chow and Gregory S. Jones, *Managing Wastes With and Without Plutonium Separation*, Report P-8035 (Santa Monica, CA: RAND Corporation, 1999). Some other studies suggest a modest benefit (perhaps 10%) from one round of reprocessing and recycling: the differences depend on detailed assumptions about such matters

as how long the spent fuel or reprocessing wastes would be stored before being emplaced in a repository, how long active cooling in the repository is assumed to continue, and the like.

¹⁹ For discussion, see “Appendix B: World Uranium Resources,” in Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing*.

²⁰ In 1997, the estimate for the sum of reasonably assured resources (RAR) and inferred resources available at \$80/kgU or less was 3.085 million tons, while in 2005 it was 3.804 million tons, an increase of 23% in eight years, despite the very low level of investment in uranium exploration until the end of that period. See Organization for Economic Cooperation and Development, Nuclear Energy Agency, *Uranium 1997: Resources, Production, and Demand* (Paris: OECD-NEA, 1998), and *Uranium 2005: Resources, Production, and Demand* (Paris: OECD-NEA, 2006). Indeed, the press release for the 2005 edition was entitled: “Uranium: plenty to sustain growth of nuclear power.”

²¹ For a cogent version of this argument for recycling, see Per F. Peterson, “Will the United States Need a Second Repository?” *The Bridge*, Vol. 33, No. 3, pp. 26-32, Fall 2003.

²² Roald A. Wigeland, Theodore H. Bauer, Thomas H. Fanning, and Edgar E. Morris, “Separations and Transmutation Criteria to Improve Utilization of a Geologic Repository,” *Nuclear Technology*, Vol. 154, April 2006, pp. 95-106.

²³ John Kessler, Electric Power Research Institute, “Preliminary Analysis of the Maximum Disposal Capacity for CSNF in a Yucca Mountain Repository,” presentation to the Nuclear Waste Technical Review Board, 8 May 2006.

²⁴ Granite formations do often have faulting in some areas that could limit the total area that could be used at a particular repository site – but sites will presumably be chosen to be far from nearby faults, and very large amounts of total material can be emplaced at typical sites of this type. Even at Yucca Mountain, there are other mountain ridges in the same area that have similar geology, and could potentially be defined as part of the “same” repository. Ultimately the issue is less the technical limits on repository capacity than the political limits on how much material can be emplaced at a particular location.

²⁵ Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing*, pp. 64-65.

²⁶ For an extensive discussion of the political history and prospects for such concepts, see Chapter 4 of Matthew Bunn et al., *Interim Storage of Spent Nuclear Fuel: A Safe, Flexible, and Cost-Effective near-Term Approach to Spent Fuel Management* (Cambridge, Mass.: Project on Managing the Atom, Harvard University, and Project on Sociotechnics of Nuclear Energy, Tokyo University, 2001; available at http://bcsia.ksg.harvard.edu/BCSIA_content/documents/spentfuel.pdf as of 18 May 2006).

²⁷ U.S. Department of Energy, *GNEP Element: Demonstrate Proliferation-Resistant Recycling* (Washington, D.C.: DOE, 2006; available at <http://www.gnep.gov/gnepProliferationResistantRecycling.html> as of 25 May 2006).

²⁸ U.S. Department of Energy, *GNEP Element: Develop Advanced Burner Reactors* (Washington, D.C.: DOE, 2006; available at <http://www.gnep.gov/gnepAdvancedBurnerReactors.html> as of 25 May 2006).

²⁹ Richard L. Garwin, “R&D Priorities for GNEP,” testimony to the U.S. House of Representatives, Committee on Science, Subcommittee on Energy, 6 April 2006.

³⁰ Bunn, Fetter, Holdren, and van der Zwaan *The Economics of Reprocessing*.

³¹ National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America’s Energy Challenges* (Washington, D.C.: National Commission on Energy Policy, December 2004, available as of June 9, 2005, at <http://www.energycommission.org/ewebeditpro/items/O82F4682.pdf>), pp. 60-61.

³² For detailed recommendations, see Matthew Bunn and Anthony Wier, *Securing the Bomb 2006* (Cambridge, Mass., and Washington, D.C.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, July 2006, available as of 16 July 2006 at <http://www.nti.org/securingthebomb>).

³³ Deutch, Moniz, et al., *The Future of Nuclear Power*.

³⁴ Nuclear Energy Study Group, American Physical Society Panel on Public Affairs, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk* (Washington, D.C.: American Physical Society, May 2005, available as of 16 July 2006 at http://www.aps.org/public_affairs/proliferation-resistance).

³⁵ For earlier discussions of this point, see, for example, John P. Holdren, “Improving US Energy Security and Reducing Greenhouse-Gas Emissions: The Role of Nuclear Energy,” testimony to the Subcommittee on Energy and Environment, Committee on Science, U.S. House of Representatives, 25 July 2000, available as of 16 July 2006 at http://bcsia.ksg.harvard.edu/publication.cfm?program=CORE&ctype=testimony&item_id=9; and Matthew Bunn, “Enabling A Significant Future For Nuclear Power: Avoiding Catastrophes, Developing New Technologies, Democratizing Decisions -- And Staying Away From Separated Plutonium,” in *Proceedings of Global '99: Nuclear Technology- Bridging the Millennia*, Jackson Hole, Wyoming, August 30-September 2, 1999 (La Grange Park, Ill.: American Nuclear Society, 1999, available as of 16 July 2006 at http://bcsia.ksg.harvard.edu/publication.cfm?program=CORE&ctype=book&item_id=2).