Assessing the Benefits, Costs, and Risks Of Near-Term Reprocessing and Alternatives

TESTIMONY OF
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Mr. Chairman and members of the subcommittee, it is an honor to be here today to discuss the Global Nuclear Energy Partnership (GNEP).

I believe that we should be working hard to fix the past problems that have limited the growth of nuclear energy, as the world may need a greatly expanded global contribution from nuclear energy to cope with the problem of climate change. I support a strong nuclear research and development program – along with greatly expanded R&D on other energy sources and efficiency.

But gaining the public, utility, and government acceptance needed for a large-scale expansion of nuclear energy will not be easy. Such an expansion will require making nuclear power as cheap, safe, secure, and proliferation-resistant as possible. I believe that while several elements of GNEP deserve strong support, the current GNEP focus on moving rapidly toward large-scale reprocessing of spent nuclear fuel will take us in the wrong direction on each of these counts, and hence is likely to do more to undermine the future of nuclear energy than to promote it.[1] Moreover, I believe that reprocessing will not be required to provide either sufficient uranium supplies or sufficient repository space for many decades to come, if then. I fear that the new focus on rushing to construction of commercial-scale facilities is precisely the wrong direction, and will distort the R&D effort. I will elaborate on each of these points in this testimony.

But first, let me emphasize the two key take-away points:

(1) We should focus first on safe, secure, and politically sustainable approaches to interim storage of spent fuel. These will be needed no matter what long-term options we choose for spent fuel management; if properly implemented, they will address the immediate needs of the nuclear industry and provide the confidence needed for construction of new reactors.

(2) We should take the time needed to make sound and politically sustainable decisions about spent fuel management. There is no need to rush to judgment. 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. From Clinch River to Wackersdorf, from Chernobyl to the Hanford tanks, the nuclear age is littered with the costly results of the rushed decisions of the past. Rushing to make decisions before the

[1] For a similar argument that the GNEP approach "threatens to set back the nuclear revival," see, for example, Richard Lester, "New Nukes," *Issues in Science and Technology,* Summer 2006, pp. 39-46.

needed analyses and R&D are completed will leave us with programs that are more costly and less effective than they could otherwise be.

Recycling in Context

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.

For spent fuel, neither recycling nor direct disposal should be supported as an article of faith. Rather, the choice should be made based on careful analyses of which options offer the best combination 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+ co-extraction technologies being considered for GNEP is inferior to once-through approaches in most of these respects. .

Costs and Financing

Reprocessing and recycling using either current commercial technologies or those proposed for GNEP would substantially increase the cost of spent fuel management. In a recent Harvard study, we concluded that reprocessing would increase spent fuel management costs by roughly 80%, compared to once-through approaches, even making a number of assumptions that were quite favorable to reprocessing.[2] A wide range of other studies, including government studies in both 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, and would likely be even more expensive.[4] The capital cost of fast-neutron reactors such as those proposed for GNEP

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[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).

[3] 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/). For a study for the French government, 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 10 September 2006 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] 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. 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, and U.S. Department of Energy, Office of Nuclear Energy, *Generation IV*

has traditionally been significantly higher than that of light-water reactors. 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."[5]

While such a cost 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, not less, 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.

The recent study by the Boston Consulting Group (BCG), arguing that reprocessing would be no more expensive than once-through approaches, is grossly overoptimistic and should not be relied on as a basis for policy.[6] The BCG study uses a wide range of unjustified assumptions to reach an estimated price for *both* reprocessing and mixed oxide (MOX) fuel fabrication of $630 per kilogram of heavy metal, far less than real commercial plants have achieved for either process. Yet the real experience of adapting French plutonium technology in the United States, the project to build a MOX plant at Savannah River, is leading to costs several times *higher* than those achieved in France, not several times lower. A more detailed critique of the BCG study is provided as an appendix to this testimony.

Proliferation Risks

In addition to being more costly, the reprocessing proposed as a central part of GNEP would raise more proliferation risks than would reliance on once-through approaches.

President Bush, like every President for decades before him, has been seeking to limit the spread of enrichment and reprocessing technologies.[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." While it is often said that the rest of the world did not listen to us, no countries have built civilian reprocessing plants that were not already reprocessing or building such facilities as of 1976, three decades ago.[8] Now, with GNEP, the message is

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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.

[5] 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.

[6] Boston Consulting Group, *Economic Assessment of Used Nuclear Fuel Management in the United States* (Boston, Mass: BCG, July 2006, available as of 11 September 2006 at http://www.bcg.com/publications/files/ 2116202EconomicAssessmentReport24Jul0SR.pdf).

[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] The major commercial reprocessing facilities in the world are in France, the United Kingdom, Russia, and Japan. The

"reprocessing is essential to the future of nuclear energy, but we will keep the technology away from all but a few states."[9] 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 be only a modest improvement, as once a country had a team of people with experience in chemically processing intensely radioactive spent nuclear fuel and a facility for doing so, this expertise and infrastructure could be adapted very rapidly to separate pure plutonium for weapons – much as countries with enrichment could readily switch from producing low-enriched uranium to producing highly enriched uranium (HEU) should they choose to do so.

GNEP advocates argue, to the contrary, that another central element of GNEP – the idea of a consortium of fuel cycle states that would provide guaranteed fuel supply and spent fuel management to other states, perhaps in a "fuel leasing" arrangement – 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.[10] Unfortunately, the way it has been presented, dividing the world forever into "fuel cycle states" that would be allowed to have these technologies and "recipient states" that would not, may be raising a danger of causing what we are trying to prevent. As I understand it, Argentina and South Africa, among others, have already suggested that they may restart their enrichment programs in part in order to be considered in the favored class of "fuel cycle states." The Subcommittee may wish to inquire of DOE whether this is correct.

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, perhaps, with Russia, which has already put in place legislation to make that possible.

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first three already had reprocessing well underway in 1976, and the Japanese Tokai plant was well advanced at that time. China and India both have some reprocessing activities, but both had reprocessing technology already in 1976. North Korea has established a reprocessing plant since 1976, but it is entirely for military purposes, not a commercial plant that might be influenced by U.S. policy on commercial reprocessing. Since 1976, a number of countries that were previously pursuing reprocessing (such as Germany and Sweden, among others) have joined the United States in abandoning reprocessing in favor of direct disposal. In general, the poor economics of reprocessing have driven decisions more than U.S. policy.

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

[10] 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); Ashton B. Carter and Stephen A. LaMontagne, "Toolbox: Containing the Nuclear Red Zone Threat," *The American Interest* (Spring 2006). 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.

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.[11] 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.[12]

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."[13]

If the administration is worried about these stockpiles of separated plutonium, they should also worry about the plutonium-uranium mixes that would be separated in the COEX process now being considered. As U.S. government examinations of the question have concluded, nuclear explosives could still be made directly from the roughly 50-50 plutonium-uranium mixes that COEX advocates refer to, though the quantity of material required for a bomb would be significantly larger. Moreover, any state or group with the capability to do the difficult job of designing and building an implosion-type bomb from pure plutonium would have a good chance of being able to accomplish the simpler job of separating pure plutonium from such a plutonium-uranium mix. The job could be done in a simple glove-box with commercially available equipment and chemicals, using any one of a number of straightforward, published processes. For these reasons, under either U.S. or international guidelines, such a mixture would still be considered Category I material, posing the highest levels of security risk and requiring the highest levels of security. When such approaches were last seriously considered in the United States three decades ago, the Nuclear Regulatory Commission concluded that "lowering the concentration of plutonium through blending [with uranium] should not be used as a basis for reducing the level of safeguards protection," and that the concentration of plutonium in the blend would have to be reduced to ten percent or less – far less than being considered for COEX – for the safeguards advantages to be

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[11] 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.

[12] 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).

[13] 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). This characterization 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." 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.

"significant."[14] The repeated statement that these processes will result in "no pure plutonium" is a talking point, not a serious analysis of proliferation and security impacts.

GNEP advocates argue that approaches such as UREX+ 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.[15] But 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 remotely radioactive enough to meet international standards for being "self-protecting" against possible theft.[16] 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.[17]

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.

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[14] Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, *Safeguarding a Domestic Mixed Oxide Industry against a Hypothetical Subnational Threat*, NUREG-0414 (Washington, D.C.: NRC, 1978), pp. 6.8-6.10.

[15] 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, many other issues should be considered in assessing proliferation resistance of a nuclear energy system, particularly as there has never yet been an historical case in which the radiation level of the material involved was the key in determining the civilian nuclear system's impact on proliferation outcomes. 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" lecture, Massachusetts Institute of Technology, 1 May 2006, available at http://bcsia.ksg.harvard.edu/BCSIA_content/documents/proliferation_resist_lecture06.pdf as of 12 September 2006.

[16] 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

[17] 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.

Safety And Security

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 – either by accident or by sabotage – than does leaving spent fuel untouched in thick metal or concrete casks. While the safety record of the best reprocessing plants is good, it is worth remembering that until Chernobyl, the world's worst nuclear accident had been the explosion at the reprocessing plant at Khyshtym (site of what is now the Mayak Production Association) in 1957, and significant accidents occurred at both Russian and Japanese reprocessing plants as recently as the 1990s. The British THORP plant is returning to operation after 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).

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.

One potential benefit of recycling is to reduce the expected doses to humans and the environment from a geologic repository. Reprocessing and recycling as currently practiced (with only one round of recycling the plutonium as uranium-plutonium mixed oxide (MOX) fuel) would not reduce such doses substantially.

Some of the approaches envisioned for the long-term track of GNEP call instead for separating all the actinides and irradiating them repeatedly in advanced burner reactors, so that all but a small percentage of the actinides would be fissioned. Some of the more troublesome long-lived fission products might be transmuted as well. If developed and implemented successfully, these approaches might provide a substantial reduction in projected long-term radiological doses from a geologic repository. 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

Advocates argue that the recycling proposed in GNEP justifies its costs and risks because, with a growing nuclear energy enterprise in the future, a once-through approach would soon run

short of either uranium or repository space. But neither uranium nor repository space is in as short supply as advocates claim.

Uranium Supply

As with environmental impact, traditional reprocessing with one round of MOX recycling has only very modest benefit in extending uranium resources. The amount of energy generated from each ton of uranium mined is increased by less than 20%.[18]

Recycling and breeding in fast neutron reactors, by contrast, could potentially extend uranium resources dramatically. But world resources of uranium likely to be economically recoverable 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] Indeed, in the last decade, the "Red Book" estimates of world uranium resources have been increasing far faster than uranium has been consumed[20] – 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.

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.

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.

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[18] 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.

[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."

Repository Space Supply

Perhaps the most important single argument for GNEP's focus on recycling is the belief that there will never be a second nuclear waste repository in the United States, so we need to figure out a way to pack all the nuclear waste from decades of a growing nuclear energy enterprise into the Yucca Mountain repository.[21]

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. If the proposed long-term GNEP approach met all of its technical goals for removing and transmuting the actinides that generate much of the long-term heat it could indeed make it possible to dramatically expand the capacity of the proposed Yucca Mountain repository.[22] Few of the technical goals required to achieve this objective have yet been demonstrated, however.

It is important to understand that traditional approaches to reprocessing, with one round of MOX recycling, would not have this benefit. 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 may actually be somewhat 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 of LEU spent fuel.[23] The spent MOX could in principle be reprocessed for transmutation in fast reactors, but that would require success in developing appropriate transmutation fuels and reactors.

In any case, 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.[24] As researchers at the Electric Power Research Institute put it: "Thus, it is possible for Yucca Mountain to hold not only all the waste from the existing U.S. nuclear power plants, but also waste produced from a significantly expanded U.S. nuclear power plant fleet for at least several decades."[25]

Moreover, whatever the merits of the repository-space argument, it applies primarily – or possibly only – 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,

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[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] 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.

[24] *Program on Technology Innovation: Room at the Mountain – Analysis of the Maximum Disposal Capacity for Commercial Spent Nuclear Fuel in a Yucca Mountain Repository* (Palo Alto, Calif: Electric Power Research Institute, May 2006, available as of 12 September 2006 at http://www.epriweb.com/public/000000000001013523.pdf)

[25] *Program on Technology Innovation: Room at the Mountain.*

if desired.[26] 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.

This argument for recycling and transmutation 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.[27]

The repository-space argument for recycling 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 substantial 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.)[28]

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[26] 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.

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

[28] 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

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.

Commercial-Scale Demonstrations and the GNEP R&D Program

A substantial R&D program to develop improved approaches to nuclear energy is justified. Such a program should include R&D on optimized approaches to spent fuel management, including both improved once-through approaches and recycling approaches. These efforts should be based on in-depth life-cycle systems analysis of different potential options, both to choose which approaches may be best and to identify the most important technical objectives for the R&D effort.

Unfortunately, however, DOE appears to be shifting its GNEP efforts to focus on building commercial-scale facilities, without having completed either the R&D on relevant technologies or the detailed systems analyses needed to make wise choices. In the request for expressions of interest issued in August, DOE envisions building a reprocessing and fuel fabrication plant known as the Consolidated Fuel Treatment Center (CFTC) with a capacity to process 2,000-3,000 tons of spent fuel per year – roughly three times the capacity of the largest single plants that currently exist – and an advanced burner reactor (ABR) that might have a capacity of 200-800 MWe.[29] In response to questions from industry, DOE indicated that it hoped to begin construction of such facilities in 2010, only four years from now.[30] The Subcommittee, in considering what direction to give DOE on this proposed approach and whether to appropriate the many billions of dollars that would be required to build these facilities, should ask a number of questions:

- Even under the very optimistic assumptions of the BCG report, would it not be reasonable to estimate that the cost of building the CFTC and the ABR would be in the range of $20 billion?[31]
- Is it not likely that cost estimates will grow substantially as the project proceeds, if it does? Can DOE provide any recent example of a DOE project of comparable scale and complexity that did not suffer the kind of cost growth that has afflicted the Hanford vitrification project and the Savannah River MOX plant?
- How does DOE expect to finance these costs? From appropriations? From the Nuclear Waste Fund? If the latter, would sufficient funds remain for Yucca Mountain?
- Is there *any* previous example in DOE's history in which the department successfully built and operated – or financed the construction and operation of – a commercial-scale facility of this complexity?

Nuclear Energy, Tokyo University, 2001; available at http://bcsia.ksg.harvard.edu/BCSIA_content/documents/spentfuel.pdf as of 18 May 2006).

[29] U.S. Department of Energy, "Notice of Request for Expressions of Interest in a Consolidated Fuel Treatment Center to Support the Global Nuclear Energy Partnership," *Federal Register*, 7 August 2006, Vol. 71, No. 151, pp. 44676-44679, and U.S. Department of Energy, "Notice of Request for Expressions of Interest in an Advanced Burner Reactor to Support the Global Nuclear Energy Partnership," *Federal Register*, 7 August 2006, Vol. 71, No. 151, pp. 44673-44676.

[30] U.S. Department of Energy, "Q&As From August 14, 2006 GNEP Industry Briefing," available as of 12 September 2006 at http://www.gnep.energy.gov/gnepCFTCABREOIBriefingQAs.html.

[31] The BCG report estimates that a facility of the same scale proposed for the CFTC would have an overnight capital cost of over $16 billion , not counting interest during construction or decommissioning. BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States*, p. 16. As described in the appendix to this testimony, the BCG figures are unrealistically optimistic. The cost to develop and build the ABR would certainly be in the billion-dollar range.

- What is DOE's past record of success and failure in picking winners among a range of possible technologies for commercial deployment? Why should we believe that this approach will be suitable in this case?
- What life-cycle systems analyses of cost, safety, security, sustainability, and proliferation-resistance led DOE to conclude that this proposed approach is preferable to other options? What independent review has there been of these analyses? Can DOE provide those analyses?
- What life-cycle analyses has DOE performed of management of the low-level and transuranic wastes that will be generated by these facilities, including from their eventual decommissioning? Would any of these wastes have to be disposed of in Yucca Mountain or WIPP? If so, how does this affect estimates of the increase in repository capacity that could be achieved?
- Does a decision to move immediately toward deployment of commercial-scale facilities mean that promising technologies still requiring significant development cannot be seriously considered for use in these major facilities? What factors led DOE to conclude it was time to choose available technologies and begin building facilities rather than continuing to pursue R&D on a range of potential separations, fabrication, and reactor technologies?
- What impact will building huge facilities using existing technologies have on R&D on long-term technologies? Is it likely that DOE will receive sufficient funding *both* to proceed directly to construction of these large facilities *and* to continue a robust research program on a wide range of technologies? Is it likely that building these large facilities would take money, personnel, and leadership focus away from long-term R&D?
- What does DOE believe this investment would buy us? How can the technologies to be pursued simultaneously be so mature that we can go straight to construction of commercial-scale facilities and so immature that they require demonstration? Does this proposal amount to spending billions of dollars to build these facilities before completing the R&D that would make it possible to know whether they would ever have the hoped-for repository benefits? If the CFTC is not expected to produce transmutation fuels, and R&D on appropriate separations, fabrication, and reactor technologies for transmutation is still under way, how confident can we be that once built, these facilities will prove to be what is needed for the transmutation mission? What does DOE plan to do if further analysis and R&D leads to the conclusion that these facilities are poorly suited to that mission?
- What would the proliferation impacts be of building these facilities? What independent review has been done of those impacts?
- Since processing 2000-3000 tons of spent fuel each year would provide some 20-30 tons of plutonium, while the ABR would likely require less than one ton per year, what does DOE plan to do with the rest of the product of the CFTC? Given that DOE is planning to spend billions of dollars on disposition of some 50 tons of excess plutonium, is there a danger of adding that amount to DOE's stockpile every two years?
- Is it really likely that the complex separations involved in UREX+, which have only been demonstrated on a kilogram scale, could be scaled to processing thousands of tons of spent fuel per year without any intermediate steps? If not, would a facility be built that uses PUREX or COEX? If so, what then happens to the objectives of separating and transmuting all of the actinides, or providing a process with improved proliferation resistance (which the Subcommittee has rightly emphasized must be maintained in the development of recycling technologies)?

As these questions suggest, I believe that what is needed now is patient R&D and in-depth systems analysis, rather than a rush to build big facilities. As Richard Garwin has put it, by picking winners prematurely, the proposed GNEP approach "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."[32]

Recommendations

What, then, should we do? I recommend the following steps:

(1) *Focus first on interim storage.* Whatever option we pursue, additional interim storage capacity will be needed. Storing spent fuel in dry casks leaves all options open for the future, as technology develops and political and economic circumstances change. (Indeed, since the Yucca Mountain repository will remain open for a century or more, even direct disposal will leave all options open for a long time to come.) At least some centralized storage capacity is needed to address particular needs; whether nearly all of the spent fuel should be moved to a centralized away-from-reactor site or site depends on a number of factors that require further analysis. Here, too, we should not let frustration with the current state of affairs prevent us from taking the time to get it right: a rushed process for siting and licensing such facilities is a recipe for public opposition and ultimate failure, adding to the long history of failed attempts to site centralized interim storage facilities in the United States. In a 2001 study, we provided a detailed outline of a democratic and voluntary process for siting such facilities, based on approaches that had been applied successfully in siting other hazardous and unwanted facilities, and I would urge that such an approach be followed here.[33] I am pleased, Mr. Chairman, that you have encouraged the American Physical Society to examine these issues in depth.

(2) *Pursue a broad R&D program to improve spent fuel management.* Someday, recycling technologies may be developed which are substantially cheaper and more proliferation-resistant than those now available. R&D should be pursued to explore such possibilities. In parallel, there should also be R&D on improved approaches to direct disposal.[34] As the technologies develop, we should regularly re-examine which of them appear to offer the best combination of cost, safety, security, proliferation-resistance, and sustainability. At the same time, we should not allow an expansion of nuclear R&D to overwhelm R&D on other promising energy technologies: the United States urgently needs to undertake expanded investments in a wide range of energy R&D.

(3) *Build political sustainability.* As it takes decades to develop and fully implement nuclear technologies, stable government policies are crucial to success. Stable policies require some degree of bipartisan consensus. The current GNEP effort has devoted virtually no noticeable effort to developing such bipartisan support. Without it, the probability of failure is high. In my judgment, approaches based on interim storage, continued R&D on a wide range of options, and continued forward movement toward a permanent repository have far better chances of being politically sustainable than approaches focused on near-term construction of reprocessing plants and fast neutron reactors.

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[32] 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.

[33] Bunn et al., *Interim Storage*, pp. 95-116.

[34] For a discussion, see Garwin, "R&D Priorities for GNEP." For a discussion of R&D that should be pursued on improved once-through options, see Deutch, Moniz, et al., *The Future of Nuclear Power*.

(4) *Move forward deliberately with the Yucca Mountain repository.* Whether we ultimately pursue once-through or recycling options, we will ultimately need a repository. We should move forward with that effort, again taking the time to get the analysis right and to build as much support as we practicably can.

(5) *Develop and analyze first, build later.* Today, technologies that might someday be able to meet the technical objective of transmuting nearly all of actinides remain in their infancy; some, like UREX+, have been demonstrated only on a kilogram scale, while others, like fabrication of transmutation fuels or construction of fast reactors with very low conversion ratios, we do not yet know are feasible. At the same time, detailed life-cycle systems analyses of the cost, safety, security, proliferation-resistance, and sustainability of the proposed technologies, compared to those of similarly advanced once-through systems, have not yet been done. To construct major facilities without first doing these system analyses is like choosing which car to buy without knowing the cost, gas mileage, reliability, or safety performance of any of the models available. GNEP should focus intensely on the kind of systems analysis that can reveal which options have critical flaws and where the greatest opportunities for R&D lie, including accelerating the development of improved systems analysis tools. *Large-scale reprocessing and transmutation facilities should not be built until detailed analysis has indicated that they offer a combination of cost, safety, security, proliferation-resistance, and sustainability superior to potential alternatives, including direct disposal.* Independent review is an important part of such analyses, and of building bipartisan support. As a first step, I recommend that in conference, the Subcommittee accept the House language calling for an in-depth peer review of the entire fuel recycling plan by the National Academies before any expensive facilities are built.

(6) *Increase the focus on other key elements of GNEP.* As noted earlier, the proposal to offer reliable guarantees of fuel supply and spent fuel management, in order to help convince countries to forego building their own reprocessing and enrichment facilities, is extremely important and should receive even more attention and effort than it has to date. Similarly, the GNEP elements related to developing advanced safeguards technologies and small, rapidly deployable reactors for deployment in developing countries should be pursued more vigorously. Neither received funding in the President's budget request, and I commend the Subcommittee for seeking to correct that omission.

(7) *Redouble key efforts to stem the spread of nuclear weapons materials and technologies.* The U.S. government should significantly increase its efforts to: (a) limit the spread of reprocessing and enrichment technologies, as a critical element of a strengthened nonproliferation effort; (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;[35] (c) work with other countries to put in place strengthened export controls and greatly strengthened intelligence and law enforcement cooperation focused on illicit nuclear trafficking, to smash what remains of the A.Q. Khan network and prevent a recurrence; (d) convince other countries to end the accumulation of plutonium stockpiles, and work to reduce stockpiles of both plutonium and HEU around the world.

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[35] 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).

In short, 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.[36]

Similar recommendations have been made in the MIT study on the future of nuclear energy,[37] and in the American Physical Society study of nuclear energy and nuclear weapons proliferation.[38]

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.[39] Those who hope for a bright future for nuclear energy, therefore, should oppose near-term reprocessing of spent nuclear fuel.

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[36] 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.

[37] Deutch, Moniz, et al., *The Future of Nuclear Power.*

[38] 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).

[39] 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).

Appendix: Brief Critique of the Boston Consulting Group Study, *Economic Assessment of Used Nuclear Fuel Management in the United States*

In July 2006, the Boston Consulting Group (BCG) published a report which concluded that the costs of reprocessing and recycling spent nuclear fuel in the United States would be "comparable" to the costs of direct disposal of spent nuclear fuel.[40] This conclusion was in stark contrast to those of most other recent studies, which concluded that reprocessing and recycling would significantly increase the costs of spent fuel management.[41] The BCG study, however, makes a wide range of unjustified assumptions, and its cost estimates should not be used as the basis for policy-making. The real cost of reprocessing and recycling in the United States would almost certainly turn out to be far higher than the costs estimated in the BCG report.

Indeed, the BCG study itself appears to agree that it should not be used as the basis for policy-making. After acknowledging that the study was initiated and paid for by Areva, the firm that operates France's reprocessing plants, and that BCG made no attempt to verify any of the data provided by Areva, the study warns: "Any other party [than Areva] using this report for any purpose, or relying on this report in any way, does so at their own risk. No representation or warranty, express or implied, is made in relation to the accuracy or completeness of the information presented herein or its suitability for any particular purpose."[42]

The BCG conclusions float on a sea of optimistic assumptions:

- BCG assumes a unit cost for *both* reprocessing and MOX fabrication of $630/kgHM (undiscounted), far lower than current plants have managed to achieve for *either* process.[43] (BCG provides, for example, an interesting chart showing that their estimate for reprocessing cost per kilogram is roughly one-third the cost actually achieved in France.[44]) As they put it themselves, one of the "key differentiating elements" between their study and other studies is "integrated plant costs significantly lower than previously published data."[45]
- By contrast, the current effort to use Areva technology and plant designs in the United States – the construction of a MOX plant at Savannah River – is leading to unit costs several times *higher* than those achieved in France.[46] This experience is not mentioned in the BCG report, and no argument is offered as to why the projected facility will have a cost result that is the opposite of the real experience.
- They reach these extremely low unit cost estimates for their projected plant by using a large number of dubious assumptions:

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[40] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States*, p. vi.
[41] See sources cited in the main text, and other sources sited therein.
[42] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States*, p. iv.
[43] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States*, p. 15
[44] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States*, p. 17
[45] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States*, p. 14.
[46] For a discussion of the remarkable cost growth of the Savannah River MOX plant, see, for example, Subcommittee on Strategic Forces, Committee on Armed Services, *Plutonium Disposition and the U.S. Mixed Oxide Fuel Facility*, U.S. House of Representatives, 109th Congress, 2nd Session (26 July 2006; available at http://www.house.gov/hasc/schedules/ as of 10 August 2006). See also U.S. Department of Energy, Office of the Inspector General, *Audit Report: Status of the Mixed Oxide Fuel Fabrication Facility*, DOE/IG-0713 (Washington, D.C.: 2005; available at http://www.ig.doe.gov/pdf/ig-0713.pdf as of 26 May 2006).

— They envision a reprocessing and MOX fabrication plant far larger than any other such plant that exists in the world, processing 2500 tons of spent fuel every year (compared to 800 tons per year in the largest single plants that have been built to date).
— They assume that plant capacity can be scaled up dramatically with only a minor increase in capital or operating cost. They note that the capital cost of the existing French facilities was $17.8 billion (in 2005 dollars), but they assume that the capacity can be increased by more than 50% (assuming, generously, that the two La Hague plants should be considered to have a combined capacity of 1600 tons of heavy metal per year) with an additional capital cost of only $1.5 billion, less than 10% of the original capital cost.[47]
— They assume that the plant will always operate at nearly full capacity with no technical problems and no contract delays. No reprocessing plant or MOX plant in the world has ever done so.
— Indeed, they apparently assume that there will never be a lag in fuel fabrication, since, to save money, they cut out all funding for having a plutonium storage area.[48] In France, by contrast, tens of tons of plutonium have built up in storage as a result of lags in the use of this plutonium as fuel.
— With a hugely increased plant capacity compared to existing plants, far higher plant utilization than existing plants, and very small increases in capital and operating costs to achieve these vast increases in throughput, it is not surprising that they find that the cost per kilogram of spent fuel processed would be much lower than the cost in existing plants. This is simply not a realistic estimate, however, of what the real costs would be likely to be if such a plant were built and operated in the United States.
— Interestingly, the capital cost they acknowledge for the existing French plants is *higher* than the estimates used in our 2003 study;[49] had they taken this actual experience as the basis for estimating future costs, they would have found reprocessing and MOX prices higher than those used in our study, not lower.
— BCG also makes dubious assumptions about the disposal and management costs of different types of nuclear waste. They argue that because of the lower long-term heat generation from reprocessing waste, compared to spent fuel, four times as much reprocessing waste could be placed in each unit area of the repository, and therefore they assume that total per-kilogram disposal costs would be only one-quarter as large.[50] As we noted in our 2003 study, however, only a portion of total disposal costs are likely to be driven by heat and repository capacity; with a four-fold repository expansion, a two-fold reduction in cost per kilogram is more appropriate.[51] At the same time as they take a four-fold cost reduction for the lower heat generation from reprocessing wastes, they assume that the management cost for spent MOX fuel would be the same as for spent LEU fuel, despite the far higher heat generation of spent MOX fuel, the greater difficulty in reprocessing it, and the much more

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[47] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States,* p. 16.
[48] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States,* p. 52.
[49] Based on published data, we envisioned a reprocessing plant that cost some $6 billion and a MOX plant with a capital cost of roughly $540 million; for two such reprocessing plants and a MOX plant, the total capital cost would then be in the range of $12.5 billion. The BCG study reports that the real capital cost of the two reprocessing plants in France (with official capacities identical to the one we considered) and the MOX plant in France (with an official capacity only modestly higher than the plant we considered) was in fact $17.8 billion, a substantially higher figure than those we used. BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States,* p. 16.
[50] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States,* p. 18.
[51] Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing,* pp. 34-45.

radioactive nature of the fuel that would be manufactured from it.[52] They acknowledge that disposing of the MOX spent fuel in the repository would effectively eliminate the repository benefit of the entire effort, because of the very high heat generation of the MOX; managing the spent MOX would require fast reactors and other technologies not included in their study.[53]

- In 1996, in the National Academy of Sciences (NAS) review of recycling and transmutation technologies, the NAS committee criticized paper estimates that predicted similarly low costs per kilogram for reprocessing, and concluded that the actual costs of real plants "provide the most reliable basis for estimating the costs of future plants."[54] BCG appears to have ignored this advice.

Government Financing and the Government's Role in the Fuel Industry

BCG also assumes that the plants they envision will be financed entirely by the government, at a 3% real rate of return. This assumption is crucial to their conclusions, as the costs of such a capital-intensive facility would increase dramatically if a higher (and more realistic) rate were chosen. As we noted in our 2003 study, if a reprocessing plant were built that had the same capital and operating costs and nameplate capacity as Britain's Thermal Oxide Reprocessing Plant (THORP), whose costs are generally similar to those of the French plants at La Hague, which are the basis for the BCG estimates, and the plant were financed at such a government rate, it would have a reprocessing cost in the range of $1,350 per kilogram of heavy metal in spent fuel (kgHM), *if* it successfully operated at its full capacity throughout its life with no interruptions (a far cry from the real experience, but the same assumption used in the BCG study). (By contrast, as already noted, BCG assumes $630/kgHM for *both* reprocessing and MOX fabrication combined.) But if the exact same plant were financed privately, at the rates the Electric Power Research Institute recommends assuming for power plants owned by regulated utilities with a guaranteed rate of return (and therefore very low risk), the unit cost would be over $2000/kgHM. If financed by a fully private entity with no guaranteed rate of return, the cost for the same facility would be over $3100/kgHM.[55] (That is *without* taking into account the large risk premium the capital markets would surely demand for a facility whose fate was so dependent on political decisions; all three of the commercial reprocessing plants built to date in the United States failed for such reasons.)

The entire approach, in short, is only financially feasible if it is fully government-financed. But for the government to own and operate a facility that would not only reprocess spent fuel but manufacture new MOX fuel on the scale they envision – providing a significant fraction of all the fuel for U.S. light-water reactors – would represent an immense government intrusion on the private nuclear fuel industry. The implications of such an approach have not been examined. The coal industry and the gas industry would surely ask, "if nuclear can get facilities to handle its waste financed at a 3% government rate, why can't we get the same thing for our environmental controls or carbon sequestration?"

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[52] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States,* p. 20.
[53] BCG, *Economic Assessment of Used Nuclear Fuel Management in the United States,* p. 20.
[54] Committee on Separations Technology and Transmutation Systems, *Nuclear Wastes: Technologies for Separations and Transmutation,* p. 421.
[55] Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing,* pp. 26-34.

Conclusion

The real costs achieved at real facilities provide the best guide to likely future costs of reprocessing and recycling in the United States. These costs are far higher than those assumed in the BCG study for an integrated U.S. plant. Policies should not be based on assuming that costs comparable to those in the BCG study are likely to be achieved in the real world.