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ENABLING A SIGNIFICANT FUTURE FOR NUCLEAR POWER:
AVOIDING CATASTROPHES, DEVELOPING NEW TECHNOLOGIES,
DEMOCRATIZING DECISIONS -- AND STAYING AWAY FROM SEPARATED PLUTONIUM

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ABSTRACT

For nuclear power to meet more than a few percent of the world's greenhouse-constrained energy needs in the 21st century would require a world of thousands of gigawatts of nuclear capacity, rather than hundreds. For such a broad expansion of fission-generated power to become broadly acceptable would require: (a) avoiding any further catastrophes, such as major reactor accidents or theft of weapons-usable nuclear material for use by proliferating states or terrorists; (b) development of new technologies that would address the complexity, cost, safety, waste management, and proliferation concerns that have so far limited utility, government, and public acceptance of nuclear power; and (c) profound transparency and democratization in nuclear decision-making, putting a better-informed public in a position to ensure that its concerns are fully addressed. To achieve both objective (a) and objective (b), the industry would be well-advised to stay away from production of additional weapons-usable separated plutonium for decades to come, as continued processing, transport, and use of tens of tons of this material every year will increase the chance of a theft or similar catastrophe, raise costs, and exacerbate political controversies. Several measures that could by taken by governments and industry to achieve these objectives are recommended.

I. Introduction

The possible futures for fission-based nuclear power can be divided into two broad categories. Along one path -- the one the world is currently on -- nuclear power's share of global energy production shrinks, and nuclear power in the 21st century will be either a niche technology providing only a few percent of world energy supply, or largely abandoned, seen as an aberration of the latter half of the 20th century. Along the other, nuclear power's share of global energy production grows, and nuclear power provides a substantial part of the answer to meeting the world's greenhouse-constrained energy needs in the 21st century.

This paper examines the steps that would be required to make the second path possible. It does not argue either for or against nuclear power, but rather outlines the objectives that would have to be met for nuclear to expand enough to provide more than a few percent of the next century's global energy needs. This question is important, for if the world energy industry is to avoid causing catastrophic climate change, while simultaneously providing the energy supplies that would be needed to alleviate the poverty that now afflicts much of the growing world population, the world will need an enormous amount of carbon-free energy in the next century. We do not yet know enough to be certain that we can provide it all without some contribution from nuclear fission. Many of the thoughts in this paper are deliberately provocative, in the hopes of encouraging discussion, debate, and new thinking.

II. Carbon-Free Energy Needs in the 21st Century: What Role for Nuclear?

Projecting energy scenarios decades in the future is an almost hopeless business. Substantial uncertainties also cloud estimates of the global climate system's likely response to increasing concentrations of greenhouse gases. Nevertheless, if the mainstream of energy modelers and the mainstream of climate scientists are even close to being correct, humankind will need a stupendous quantity of carbon-free energy in the 21st century. And from the perspective today of a world that is more than 85% dependent on fossil fuels for commercial energy supply, it is not at all obvious where this carbon-free energy is going to come from. As the nuclear industry has been pointing out for years, nuclear power may provide one part of the answer. (The "nuclear industry" is anything but monolithic, and my use of the term in this paper admittedly represents a substantial oversimplification, lumping together a variety of firms whose interests in some areas overlap and in others diverge.)

Dr. Steve Fetter, in a paper entitled Climate Change and the Transformation of World Energy Supply, has examined a wide range of projections of future energy demand and a wide range of estimates of the sensitivity of the climate system to greenhouse gas concentrations. He concludes that to avoid major risks of potentially catastrophic effects of climate change, it would be necessary to stabilize atmospheric concentrations of CO_2 in the range of twice pre-industrial concentrations, and that to do this carbon-free sources of energy would have to grow from 14 percent of commercial energy supply today to 60-80 percent of a doubled or tripled supply by 2050.[1] That is, some combination of nuclear, renewables, and fossil fuels with sequestration of CO_2 would have to grow from 53 exajoules (EJ) per year in 1995 to 500-1000 EJ/yr by 2050 -- a phenomenal growth rate of 4-5.5 percent per year sustained over the entire period. By 2100, the carbon-free energy demand would rise to 600-2600 exajoules per year (the uncertainty increasing as the time becomes even more remote).

Today, nuclear power is providing about 26 EJ/yr, from over four hundred plants worldwide -- a substantial amount of energy in absolute terms, but trivial by comparison to these estimates of the amount of carbon-free energy the world will need by mid-century. For nuclear to provide even a third of the mid-range estimate for the world's carbon-free energy needs in 2050 -- meaning that the world would still have to look elsewhere for two-thirds of its carbon-free energy -- would require scaling nuclear power up tenfold. If nuclear's share remained only a fraction of that level, it would not be playing a really essential role in meeting the world's energy demand; a technology that provides only a few percent of the world's primary energy needs is a technology that over the course of a few decades could easily be replaced by a modest expansion of other energy sources.

Yet for nuclear to provide even one-third of the carbon-free energy supply would require adding an average of over 70 gigawatts-electric (GWe) of nuclear capacity every year, year after year, for five decades. Since there is no prospect whatever of growth rates even resembling that figure for at least the next two decades, what would actually be required is a very rapid transition from near-stagnation in the near term to even higher rates of capacity addition, possibly over 100 GWe per year, over the latter part of the period. While projections by the IAEA and the World Energy Council have included growth to nearly these levels within the range of possibilities,2 I think everyone in this room would agree that this would be a very tall order, and could not occur without some fundamental changes compared to where the nuclear industry finds itself today.

In short, if nuclear power is to play a really essential part in addressing the greenhouse problem, slow, steady growth (a goal the industry would be lucky to meet in the near term) will not be enough -- rapid, unprecedented rates of growth would be required. What would have to be done to make that possible?

III. Avoiding Catastrophes

The first and most obvious part of the answer is that further catastrophes such as the Chernobyl accident would have to be avoided. Another accident on the scale of Chernobyl would have a devastating impact on the nuclear industry worldwide, regardless of arguments such as those made after Chernobyl that the rest of the world's nuclear industry was much safer than the industry wherever the accident occurred. Such an event would kill any prospect for large-scale expansion of nuclear power, and the possibility of widespread shut-downs of existing plants would be very real.

Yet today, there are still 26 of the oldest-design Soviet-designed power plants in operation -- 14 of the RBMKs and a dozen of the VVER-440-230s. The safety of these facilities has been improved in a variety of ways since the Chernobyl accident, but the fact is that they have no containment vessels and inadequate to non-existent emergency core cooling systems. Moreover, reactors in the former Soviet states in general do not have the same level of safety system redundancy, modern control systems, or fire protection found in Western plants -- and are being operated and regulated by people whose pay is shockingly low and often delayed for months at a time.3 Genuine safety risks exist elsewhere, as well: in China, for example, projected rapid growth is to occur in a context where there is little background in civilian nuclear management and a history of ineffective safety and environmental regulation, and international peer reviewers have expressed concern over safety practices.

While the international community has made a substantial cooperative effort to address these safety issues, and considerable progress has been made -- with a significant contribution from the nuclear industry, and in particular the World Association of Nuclear Operators (WANO) -- the pace, funding, and scope of the effort does not match the scale of the need. As just one example, the issue of funding for the shut-down of the Chernobyl reactors continues to drag on, year after year, leaving Ukraine's pledge to shut these reactors down next year very much in doubt.

Given the potentially devastating consequences to the world nuclear industry of another major accident, I would argue strongly that the industry, in its own interests, should be aggressively lobbying national governments to spend more on getting the needed safety improvements done, and shutting down those reactors that simply cannot be made safe enough to meet international standards. In the long run, lobbying spent on that objective may do much more to ensure the industry's future than lobbying to modify the latest regulatory wrinkle impeding cost reduction in a particular segment of a particular country's industry -- which is where most of the industry's effort is focused today. Indeed, I believe that an enlightened view of the industry's self-interest would suggest that additional investments of the industry's own money in this effort would, in the long run, have a positive rather than a negative impact on the bottom line. I believe there are enormous opportunities for WANO, in particular, to do more to work with operators in the former Communist states, in China, and elsewhere to improve safety. An accident anywhere is a problem for everyone.

Similarly, a theft of plutonium or HEU from a civilian program somewhere that really led to a rogue state or terrorist group being able to make a nuclear bomb -- or, worse yet, that led to the actual use of a nuclear bomb -- would also be a catastrophe not only for world security, but for the nuclear industry's prospects. World reaction to such an event would dwarf the reaction to India's use of reactors provided for ostensibly civilian purposes to produce plutonium for its 1974 test. Public reaction against civilian operations handling weapons-usable separated plutonium would likely be swift and overwhelming, and would likely spill over to the nuclear power industry in general, as the linkage in the public mind between nuclear power and nuclear weapons dangers was brutally reinforced. Once again, after such an event the prospects for gaining acceptance for the kind of rapid growth required for nuclear to play a significant part in providing mankind's greenhouse-constrained energy needs in the 21st century would be reduced to almost nil, and widespread shutdowns of existing facilities would be a distinct possibility.

Yet here too, the danger is all too real. While the entire international community has an overwhelming interest in making sure that all weapons-usable nuclear material is secure and accounted for, wherever it exists, security for nuclear material has traditionally been regarded as a purely national concern. As a result, there are no mandatory international standards for security for weapons-usable worldwide, and no means for the international community to confirm that reasonable standards of security and accounting are being met -- and in fact, security and accounting practices vary widely from one country to the next.[4] In a world in which both terrorist organizations and the procurement networks of proliferant states have demonstrated a global reach and an ability to search out the weak points, this should be a major concern.

While this is a global issue, the most urgent risks today appear to lie in the former Soviet Union, where security and accounting systems have been greatly weakened by the collapse of the Soviet system and the consequent political and economic upheavals. Much of the fissile material in Russia is in facilities with no effective portal monitor at the door to set off an alarm if some one walks out with plutonium or HEU; poorly trained, conscript guard forces go unpaid for months at a time; no major facilities have carried out a measured physical inventory in this decade; electricity that provides the lifeblood of alarm and sensor systems is sometimes cut off for non-payment of bills; and all this takes place in a society where corruption is endemic and violent organized crime groups with extraordinary resources control large sections of the economy.[5]

Here, too, major cooperative programs have been underway for several years to address the danger (primarily in the former Soviet Union, but to a modest degree elsewhere as well), and considerable progress has been made -- but most of the work remains to be done, and the scale and pace of the effort do not come close to matching the seriousness and urgency of the threat. In this case, with a few notable exceptions -- such as BNFL's excellent work on material accountancy with the Mayak Production Association in Russia -- most of the firms in the nuclear industry whose main business is not safeguards have done very little to address the issue. Industry has been enthusiastic in responding to the prospect of disposition of excess weapons plutonium -- because of the possibility of creating a visible connection between the civilian nuclear industry and the prospects for disarmament, and the possibility of getting paid for the service of irradiating weapons plutonium. But essential as disposition is, it is far less urgent than making sure all the material is nailed down long enough to be dispositioned. In building support for the funding necessary to do that job, I am sorry to report that the industry's voice has been very, very quiet.

Indeed, while the U.S. government has been seeking to strengthen international standards for securing weapons-usable material, the nuclear industry in many countries has been actively resisting these needed reforms. Examples range from the resistance to modifying the Physical Protection Convention to cover material in domestic use and make it mandatory to meet IAEA recommendations for securing nuclear material, to the opposition to including a recommendation for armed guards or any specificity with regard to the threats that should be protected against in those IAEA recommendations, to the unwillingness to make use of the armed escort vessel that had already been built to guard the most recent MOX shipment from Europe to Japan. Yes, all of these steps raise at least the possibility of additional cost; but the costs involved are minor compared to the risks to the world and the industry if inadequately protected nuclear material anywhere were to be stolen and fall into the wrong hands. The industry is being penny-wise and pound foolish. In its own self-interest, I believe the industry should reverse course and lobby hard for stringent and transparent international standards of security and accounting for all nuclear material, and funding for the international cooperation needed to help states meet those standards, making it possible to demonstrate to the public that this risk is being effectively guarded against.

IV. Developing New Technologies To Address Past Concerns

Secondly, to achieve the kind of rapid growth that would make nuclear power an essential player in the world's 21st century energy picture, fundamentally improved nuclear technologies would have to be developed. As a panel of the President's Committee of Advisors on Science and Technology (PCAST) pointed out in their report on Federal Energy Research and Development For the Challenges of the Twenty-First Century, "several problems cloud fission's potential as an acceptable power source today and into the future: disposal of radioactive waste; concern about nuclear weapons proliferation; concern about safe operation of plants; and noncompetitive economics."[6] Quite fundamental improvements in each of these four areas are likely to be needed if nuclear power is ever to achieve the broad acceptance that would be needed for the phenomenal growth described above to become a plausible future.

Unfortunately, as Fetter has pointed out,[7] the structure of the nuclear debate has inhibited technical re-thinking in these areas. Nuclear supporters generally believe that these issues are political, not technical, as current reactors are already extremely safe, waste management poses negligible risks, proliferation risks are theoretical at best and countries will get nuclear weapons if they want them regardless of what fuel cycle technologies are pursued, and the high cost of nuclear power is driven by unjustified regulatory delays and requirements. Nuclear critics, by contrast, believe that nuclear power is so fundamentally flawed that no amount of R&D will fix it.

I believe that both of these views leave out critical parts of the picture. What may be safe enough for a world of hundreds of reactors is not safe enough for a world of thousands of reactors, and what may be proliferation-resistant enough for a world of hundreds of reactors where tens of thousands of nuclear weapons already exist is not likely to be proliferation-resistant enough for a world with thousands of reactors where reductions to a few hundred nuclear weapons or even to zero are being seriously pursued. Moreover, the experience of the past two decades has made clear that not only safety but demonstrable safety, simple enough to be clearly understood by a wide audience, is what will be needed for public acceptance. While that is a tall order, I do not believe anyone knows enough yet to be sure that all the carbon-free energy the world is likely to need can be provided without a contribution from nuclear power: as the PCAST panel concluded, "given the projected growth in global energy demand as developing nations industrialize, and the need to stabilize and then reduce GHG [greenhouse-gas] emissions, it is important to establish fission energy as an acceptable and viable option, if at all possible."[8]

I respectfully submit that modest improvements on the light-water reactor and the sodium-cooled breeder, desirable though they may be, are not going to be enough. I believe it is extremely unlikely that these ideas of the first generation of nuclear technology will ever have the combination of simple, demonstrable, inherent safety and low cost that would be pre-conditions for large-scale utility purchases of new nuclear power plants around the world.[9] The current near-hiatus in new construction of nuclear plants should be seen as an opportunity to go back to the drawing board and develop a fundamentally new generation of nuclear technologies.

This will, of course, require significant government investments in nuclear R&D, with a focus on new ideas holding out the potential for major improvements in simplicity, safety, cost, waste management, and proliferation resistance. The PCAST panel recommended a sensible U.S. R&D strategy combining (a) a program focused on new ideas for major improvements, with projects proposed by universities, laboratories and industry selected competitively, initially funded at $50 million a year and increasing to $100 million per year by 2002; and (b) a $20 million/year R&D program (half from government, half from industry) to address the problems that might prevent current plants from continuing to operate. The first portion of this recommendation was the origin of the Department of Energy's Nuclear Energy Research Initiative (NERI), currently funded at a level substantially below what PCAST recommended. Others have recommended an even more substantial program focused on similar issues.[10]

A number of other countries, particularly Japan and France, have nuclear R&D programs that dwarf the U.S. effort. A very large fraction of these R&D programs in recent years -- as with U.S. R&D programs in the more distant past -- has been devoted to plutonium recycling and sodium-cooled breeder systems. Given the large supplies of uranium that exist in the world, these systems are not going to be economically justified for decades, if then, and it is highly questionable that they will ever gain the broad acceptance that would be required for large-scale growth of nuclear power. I would argue that this money would be better spent, and better ensure these nations' technological leadership in the 21st century, if a substantial fraction of this effort were redirected toward financing new ideas to address the four key issues -- safety, proliferation, waste management, and cost -- identified in the PCAST report. It is notable that the PCAST report specifically declined to support any further U.S. R&D on sodium-cooled breeders, even the more proliferation-resistant variety that had been under development in the U.S. program.

What types of concepts should such R&D focus on? A few key priorities:

- Reactors that simply cannot create off-site fatalities from acute radiation exposure, no matter what the operators do -- and where this feature is based on simple and easily demonstrated principles.
- Proliferation-resistant means of extending the uranium resource in the long term -- systems designed to, in effect "breed in place," achieving far higher creation and consumption of plutonium in a once-through mode; systems for recycling that are incapable of extracting fissile material in a weapons-usable form (or providing much of the basis for doing so with modifications); cost-effective means for recovery of the vast quantities of uranium in seawater (see below).
- Simple, demonstrably safe approaches to waste management -- both interim storage and final disposal[11]
- New approaches to reducing cost.

There is no shortage of new ideas out there, as the NERI submissions make clear. In my own view, some of the concepts for high-temperature gas-cooled systems with lifetime cores and only the most minimal operator requirements seem particularly interesting. Some of these new ideas may prove to be attractive; others probably will not. R&D will be necessary to find out, and to fully develop systems that appear to offer genuine promise.

Let me close this part of the discussion with a warning against technical complacency. In some quarters of the nuclear industry, I sometimes hear an argument which, boiled down, comes to this: "nuclear technology doesn't have to change much, because the world won't have any choice but to come to nuclear if it wants clean power -- the cheap natural gas has to run out eventually, and solar will never catch us on price or ability to provide baseload power." I would caution against too great reliance on these kinds of assumptions about nuclear's competitors.

In the specific case of natural gas, there are enough conventional resources left to last for decades yet, and the resource that exists in methane hydrates is thought to be more than all conventional resources of fossil fuel combined. While hydrates are not a commercially viable source today, in mid-1998, DOE published a strategic plan for hydrates R&D (inadequately funded at present, to be sure, just as nuclear R&D is) designed to make possible commercial production of natural gas from hydrates by 2015.[12] If recovery of gas from hydrates and sequestration of CO_2 both prove to be do-able at reasonable economic and environmental cost, the competition from natural gas -- at somewhat higher prices than today's -- may go on essentially indefinitely.[13] Similarly, solar photovoltaics, while not competitive for baseload grid-connected applications today, have been achieving cost reductions over the last two decades at a rate very substantially faster than nuclear technology can claim -- and there seem to be some prospects for this to continue for some time to come. While the lack of cost-effective electricity storage technologies poses a major obstacle to solar for the near future, it is certainly within the realm of the possible that new technologies will be available for that purpose in two or three decades time. Indeed, Shell International Petroleum Company -- hardly a firm with a financial incentive to exaggerate the potential of non-fossil technologies -- has laid out scenarios in which solar and other renewable technologies would provide one-half to two-thirds as much energy worldwide as fossil fuels do today by 2025, and would continue to increase their share thereafter.[14] In short, the nuclear industry will have to innovate if it is to survive and compete; it cannot rest on its laurels.

V. Democratizing Nuclear Decision Making

Finally, a profound change in public attitudes toward nuclear power would be necessary for nuclear power to achieve this kind of growth. I find it remarkable that when I ask leading figures in the nuclear industry anywhere in the world what the major obstacles to the industry's success are, public attitudes toward nuclear power is virtually always close to the top of the list -- yet with a few exceptions the industry has no one but engineers and hired-gun public relations firms working on the problem.

Better PR, as important as it may be, will not solve the nuclear industry's problems with the public. (Indeed, a strong case can be made that misleading PR campaigns have contributed to the public's distrust.) Industry officials often say the need is for better public education -- which implies that the industry has the truth, the public does not, and what is really needed is a better mechanism to transmit that truth from industry to public. What is really needed, instead, is a better way to transmit ideas and concerns in both directions, and then integrate the public's ideas and concerns into decisions about nuclear and other energy technologies.

A major effort is required to understand the roots of the public's attitudes toward nuclear technology, to compare this to the development of public attitudes toward other hazardous technologies, to compare these factors across countries and cultures, and to examine the successes and failures of different approaches that have been taken over time to address public concern and integrate that concern into nuclear decision-making. That effort, I shudder to say, will require serious social and political scientists, not engineers and PR people. I believe the nuclear industry would be well-advised to start today to work with government, academia, and non-government organizations to launch such an effort -- though it may turn out that such an effort, to be effective, will have to be totally independent of the nuclear industry and funded by other sources.

Nuclear technology -- both military and civilian -- is inherently a difficult subject for democracies to grapple with. Today, much of the information needed for informed decisions is either secret, commercially proprietary, or too complex for most members of the public to fully understand. We should work to reduce these barriers, declassifying information, releasing broad categories of data now considered proprietary, and organizing the information in ways that allow it to be found and understood. (I regard it as particularly remarkable, for example, that although both COGEMA and BNFL are state-owned firms operated for the benefit of the French and British taxpayers, those taxpayers are not allowed to know even the basics of the detailed cost-benefit calculations that factor into decisions on whether to build and operate new plants.) Most important, if the nuclear industry is ever to win the public's confidence, it will have to do far better at honestly, candidly, and quickly relaying the bad news, relating to accidents, releases, and the like. The kinds of lies and cover-ups that followed the Chernobyl accident, or even the recent incidents at plutonium facilities in Japan, simply cannot be allowed to recur.

Ultimately, I believe that even with radically simpler, safer, cheaper, more proliferation-resistant technology, nuclear power will not achieve the broad public, government, and utility support needed to be a major player in the 21st century unless there is a radical democratization of nuclear decision-making, putting a well-informed public in a position to ensure that its concerns are adequately addressed at every step of the way. Many of the nuclear countries are groping toward this general idea, trying to find ways to integrate public concerns into decision-making -- from the round-table talks in Japan, to the inter-party consensus talks that were attempted in Germany, to the DOE's Openness Initiative and enormously expanded use of the public consultation provisions of the National Environmental Policy Act in the United States. I don't believe any country or organization is fully satisfied that they've found a workable solution. This is one of the great intellectual challenges for those of us who think about nuclear policy.[15]

VI. Minimizing Reliance on Separated Plutonium

Finally, let me make a point that, in this audience, may be the most controversial yet. Since the dawn of the nuclear age, nuclear experts have believed that world supplies of uranium were limited, and that therefore if nuclear power was to have any future, plutonium recycling was essential. To be against recycling plutonium was seen as essentially equivalent to being against nuclear power.

I believe that for the next several decades at least, nearly the opposite will be true -- that undue reliance on separated, weapons-usable plutonium will place nuclear power's future at risk, and that those who hope for a bright future for nuclear power would do well to minimize the separation and use of separated plutonium rather than promoting it. Nuclear power's future will be best ensured by making it as catastrophe-proof, cheap, and uncontroversial as possible -- and recycling of separated plutonium fails on all three counts.

First, despite the remarkable progress of safeguards technology, a world in which tens of tons of separated, weapons-usable plutonium is being produced, processed, and shipped from place to place every year when a few kilograms is potentially enough for a bomb clearly poses greater proliferation risks than a world in which that is not occurring. The risks that some plutonium might fall into the wrong hands -- and that this event would be catastrophic not only for security but also for the nuclear industry -- cannot be ignored.

Let me be clear that reactor-grade plutonium is weapons-usable, at all levels of sophistication. This is a point that some in the nuclear industry continue to obfuscate or misunderstand, arguing that while a sophisticated country like the United States might be able to use such lousy material for a bomb, surely a terrorist would not be able to do so -- or, on the other hand, that one might be able to make a bomb from such material good enough for a terrorist or rogue state, but not weapons that any serious country would want to have in their arsenal.16 These arguments are simply technically incorrect, and making them only undermines the industry's credibility.

For an unsophisticated proliferator, making a crude bomb with a reliable, assured yield of a kiloton or more --and hence a destructive radius about one-third to one-half that of the Hiroshima bomb— from reactor-grade plutonium would require no more technology or sophistication than making a bomb from weapon-grade plutonium. A somewhat more sophisticated proliferator could readily make bombs from reactor-grade plutonium with substantially higher reliable, assured yields. And major weapon states like the United States and Russia could, if they chose to do so, make bombs from reactor-grade plutonium with yield, weight, and reliability characteristics similar to those made from weapons-grade plutonium. That they have not chosen to do so in the past has to do with convenience and a desire to avoid radiation doses to workers and military personnel, not the difficulty of accomplishing the job. The United States has recently declassified an unprecedented level of detail on this subject.17 My colleagues from the National Academy of Sciences panel on plutonium disposition and I have spoken not only to designers from all three of the U.S. weapons laboratories on this subject, but also to weapons designers from all five of the declared weapon states; I think it is safe to assert that these points are not in dispute among weapon designers who have looked into the matter. Indeed, one Russian weapons-designer who has focused on this issue in detail criticized the information declassified by DOE for failing to point out that in some respects it would actually be easier for an unsophisticated proliferator to make a bomb from reactor-grade plutonium (as no neutron generator would be required).

Second, with relatively low uranium prices, which are projected to continue for the foreseeable future, a once-through fuel cycle is clearly more cost-effective than a reprocessing fuel cycle. There is clearly enough uranium in conventional resources, available from secure and diversified global supplies, to fuel even rapid growth of nuclear power for decades, at prices well below the break-even prices at which recycling in either thermal or fast reactors would be competitive. Indeed, recent work in both France and Japan suggests that it may be possible to recover uranium from seawater for as little as $80-$100 per kilogram of uranium; if such estimates proved to be even within a factor of two or three of the mark, recycling might never become economic unless its costs could be drastically reduced.18 Thus, for decades to come, reprocessing and recycling separated plutonium will not only be contrary to the objective of minimizing the risk of catastrophes, it will also be contrary to the objective of reducing cost.

Finally, from the United States to Germany, from Britain to Japan, reprocessing and recycling of plutonium is also a lightning rod for controversy, on both environmental and security grounds. This is something the nuclear industry surely does not need. In particular, plutonium recycling is so political that I believe it would be very poor policy for any country to rely on it as a path to energy security. If energy security means anything, it means that your energy supplies will not be disrupted by events beyond your 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. If anything, plutonium recycling is much more vulnerable to external events than reliance on once-through use of uranium, whose supplies are diverse, plentiful, and virtually impossible to cut off.

Today, tens of tons of weapons-usable plutonium are already being separated each year in the civilian industry, and over 180 tons are in store, awaiting final disposition. This situation will not be turned around overnight; the hazards, costs, and controversies of these activities will be with us for quite some time to come. But it would be sensible not to add to them more than necessary.

This does not mean, in my view, that it is impossible that there will ever be approaches to recycling and consuming plutonium that make security, economic, political, and environmental sense. R&D should explore such possibilities. But the technologies of today, which involve plutonium in forms directly usable in nuclear weapons, are not technologies that will ever prove acceptable enough to support large-scale growth of nuclear power. I am encouraged that support for this view is growing; even the Russian Minister of Atomic Energy, for example, has said publicly that the risk of theft of weapons-usable nuclear material is "one of the key problems of the non-proliferation regime," and that therefore "no matter how efficient the inspection and safety regime in different countries may be it is necessary to pass on to a different kind of technological cycle in nuclear energy that has built into it a mechanism to prevent the development of weapons-grade materials."[19]

VII. Final Words

In short, achieving the kind of growth that would make nuclear power an important player in meeting the world's greenhouse-constrained energy needs in the 21st century is a very tall order. It remains possible that this challenge will not be met, leaving nuclear power either as an inessential niche technology providing only a few percent of the world's energy needs, or abandoned entirely. If nuclear power is to meet the challenge, it will be essential to avoid new catastrophes, develop fundamentally improved technologies to address past concerns, and radically democratize nuclear decision-making. And it would be highly desirable to move away from the proliferation risks, costs, and controversies of separating, transporting, and using additional weapons-usable plutonium.

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Endnotes

1 Steve Fetter, Climate Change and the Transformation of World Energy Supply, Stanford, CA: Center for International Security and Cooperation, Stanford University, forthcoming (available at http://www.puaf.umd.edu/papers/fetter/publications.htm). Fetter concludes that only four carbon-free energy sources have the potential to expand enough to meet large portions of this demand by 2050: fission, solar, biomass, and fossil fuels with sequestration. He then lays out the strengths

and weaknesses of each, and possible R&D plans to address the obstacles. See also Steve Fetter, "Climate Change and the Future of Nuclear Energy," paper presented to the Pugwash Conferences on Science and World Affairs, Meeting No. 244, "The Prospects of Nuclear Energy," Paris, December 4-5, 1998 (available at the same address).

2 In scenarios developed by the IAEA and the WEC, nuclear contributes up to 2000 GWe or 150 EJ/yr of primary energy by 2050, and 6000 GWe or 450 EJ/yr by 2100. See International Atomic Energy Agency, Nuclear Power: An Overview in the Context of Alleviating Greenhouse Gas Emissions, IAEA-TECDOC-793, Vienna: IAEA, 1995; World Energy Council and International Institute of Applied Systems Analysis, Global Energy Perspectives to 2050 and Beyond, London: WEC, 1995.

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4 See Matthew Bunn, "Security for Weapons-Usable Nuclear Materials: Expanding International Cooperation, Strengthening International Standards," in Comparative Analysis of Approaches to Protection of Fissile Materials: Proceedings of a Workshop at Stanford California, July 28-30, 1997, Livermore, CA: Lawrence Livermore National Laboratory, Document Conf.-9707121, May 1998 (available at http://ksgnotes1.harvard.edu/BCSIA/Library.nsf/atom). See also George Bunn, "Physical Protection of Nuclear Materials: Strengthening Global Norms," IAEA Bulletin, 39/4/1997.

5 For discussions, see Matthew Bunn, "Urgently Needed Next Steps to Control Warheads and Fissile Material," in Joseph Cirincione, ed., Repairing the Regime, Washington DC: Carnegie Endowment for International Peace, forthcoming (available at http://ksgnotes1.harvard.edu/BCSIA/Library.nsf/atom), and sources cited therein.

6 Federal Energy Research and Development For the Challenges of the Twenty-First Century, Washington DC: President's Committee of Advisers on Science and Technology, 1997, p. 5-2 (available at http://www.whitehouse.gov/WH/EOP/OSTP/Energy). See also the follow-on report that specifically addresses international cooperation in energy research, development, demonstration, and deployment: Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation, Washington DC: President's Committee of Advisors on Science and Technology, May 1999.

7 Fetter, "Climate Change and the Future of Nuclear Energy," op. cit.

8 PCAST, Federal Energy Research and Development, op. cit.

9 For an interesting discussion on this point, see Lawrence M. Lidsky and Marvin M. Miller, "Nuclear Power and Energy Security: A Revised Strategy for Japan," paper presented to the PARES Workshop, Energy Security in Japan, Tokyo, Japan, July 13, 1998. See also Lawrence

M. Lidsky, "Nuclear Power in a World With Options," paper presented at the Symposium on [R]Evolutionary Reactor Types, Ultra-Centrifuge Nederland N.V., Almelo, NL, May 29, 1991.

10 See, for example, Fetter, "Climate Change and the Future of Nuclear Energy," op. cit.

11 While I concur with 1994 recommendation of the Committee on International Security and Arms Control of the National Academy of Sciences (Management and Disposition of Excess Weapons Plutonium, Washington DC: National Academy Press) that research on systems that may offer the potential to transmute essentially all of the actinides in nuclear waste should be supported "at a conceptual level," I do not rank this work among the top priorities, because of my skepticism that transmutation systems will ever be simple and cost-effective enough to gain widespread utility, government, and public acceptance. For a review of these concepts, see National Research Council, Committee on Separations Technology and Transmutation Systems, Nuclear Wastes: Technologies for Separation and Transmutation (Washington DC: National Academy Press, 1997).

12 A Strategy for Methane Hydrates Research and Development, U.S. Department of Energy, Office Of Fossil Energy, August 1998.

13 Sequestration is looking more and more like a realistic possibility. For a recent discussion, see Carbon Sequestration: State of the Science, Washington DC: Department of Energy, Office of Fossil Energy, April 1999.

14 Shell International Petroleum Company, The Evolution of the World's Energy System 1860-2060, London, UK: Shell Centre, Briefing Paper, December 1995.

15 See, for example, David P. O'Very, Christopher E. Paine, and Dan W. Reicher, eds., Controlling the Atom in the 21st Century (Boulder, CO: Westview Press, 1994). This problem is also one of the major foci of the Project on Managing the Atom at Harvard University, with the efforts in this area led by project director Jennifer Weeks. See the description at the project's web page, at http://www.ksg.harvard.edu/bcsia/atom.

16 Unfortunately, more than twenty years after the essential facts were declassified, obfuscation on this point is not a matter of a few isolated holdouts in the industry. Even the official COGEMA web page (http://www.cogema.fr) features incorrect information as to why reactor-grade plutonium is "particularly unsuitable" as weapon material.

17 U.S. Department of Energy, Office of Arms Control and Nonproliferation, Final Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives, Washington DC: DOE/NN-0007, January 1997, pp. 37-39.

18 Steve Fetter, Matthew Bunn, and John P. Holdren, The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel, Cambridge, MA: Project on Managing the Atom, Harvard University, 1999.

19 Press conference transcript, Nov. 25, 1998