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Insurmountable Risks

Can Nuclear Power Solve the Global Warming Problem?

BY BRICE SMITH[1]

Climate change is by far the most serious vulnerability associated with the world's current energy system. While there are significant uncertainties, the possible outcomes of global warming are so varied and potentially so severe in their ecological and human impacts that immediate precautionary action is called for.

Compared to fossil fuels, nuclear power emits far lower levels of greenhouse gases even when mining, enrichment, and fuel fabrication are taken into consideration.[2] As a result, some have come to believe that nuclear power should play a role in reducing greenhouse gas emissions.

The most important practical consideration, rarely addressed in the debate, is this: how many nuclear power plants will it take to significantly impact future carbon dioxide emissions from fossil fuel power plants? We have considered in detail two representative scenarios for the future expansion of nuclear power. The assumed worldwide growth rate of electricity is the same for both, 2.1 percent per year, comparable to values assumed in most conventional studies of the electricity sector.

Nuclear growth scenarios

The first scenario was taken from a 2003 study from the Massachusetts Institute of Technology.[3] In this report, the authors envisioned a "global growth scenario" with a base case of 1,000 gigawatts (GW) of nuclear capacity installed around the world by 2050. Since all of the reactors in operation today would be shutdown by mid-century, this would represent a net increase of roughly a factor of three over today's effective capacity. To give a sense of scale, this proposal would require one new reactor to come online somewhere in the world every 15 days on average between 2010 and 2050.

Despite the increase in nuclear power envisioned under the global growth scenario, the proportion of electricity supplied by nuclear power plants would increase only slightly, from about 16 percent to about 20 percent. As a result, fossil fuel-fired generation would also grow and *the emissions of carbon dioxide, the most important greenhouse gas, from the electricity sector would continue to increase.*

In order to consider a more serious effort to limit carbon emissions

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INSIDE

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Photovoltaic panels at Oberlin College, Oberlin, Ohio. *This building includes 4,682 square feet of PV panels, closed-loop geothermal wells for heating and cooling, and a wastewater treatment system modeled on natural wetland ecosystems.*

Low-Carbon Diet for France

Hold the Nukes

BY ANNIE MAKHIJANI AND ARJUN MAKHIJANI

France is the iconic country for nuclear power advocates. It gets nearly 80 percent of its electricity from 58 nuclear reactors. It reprocesses spent fuel to recover plutonium and uses it as mixed oxide fuel (plutonium dioxide mixed with depleted uranium dioxide), called MOX fuel for short.

France got rid of the use of oil in its electric power sector in 1973. Because of very low carbon dioxide (CO_2) emissions in its electric power sector, due to the predominance of nuclear power and

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through the use of nuclear power, we developed the "steady-state growth scenario." Using the same electricity demand growth assumed in the MIT report, we calculated the number of nuclear reactors that would be required to simply *maintain* global carbon dioxide emissions at their year 2000 levels.

Considering a range of assumptions about the future contribution of renewables and natural gas fired plants, we found that between 1,900 and 3,300 GW of nuclear capacity would be required to hold emissions constant. For simplicity we used 2,500 GW as the alternative case study. This scenario is roughly equivalent to assuming that nuclear plays about the same role in the global electricity sector in the year 2050 as coal does today in the United States.

In order to significantly *reduce* carbon dioxide emissions, nuclear power plant construction would have to be more rapid than one a week. We have not considered such scenarios, since the dangers of using nuclear energy to address greenhouse gas emissions are amply clear in the two scenarios discussed here.

Evaluating the scenarios

Given that both time and resources are limited, a choice must be made as to which sources of electricity should be pursued aggressively and which should not. The best mix of alternatives will vary according to local, regional, and country-wide resources and needs. In making a choice, the following should serve to help guide the selection:

1. the options must be capable of making a significant contribution to a reduction in greenhouse gas emissions, with a preference given to those that achieve more rapid reductions;
2. the options should be economically competitive to facilitate their rapid entry into the market; and,
3. the options should minimize other environmental and security impacts and should be compatible with a longer term vision for creating an equitable and sustainable global energy system.

In order to significantly reduce carbon dioxide emissions, nuclear power plant construction would have to be more rapid than one a week.

It is within this context that the future of nuclear power must be judged.

Security

The largest vulnerability associated with a large expansion of nuclear power is likely to be its connection to the potential proliferation of nuclear weapons. In order to fuel the global or steady-state growth scenarios, the world's uranium enrichment capacity would have to increase by approximately two and half to six times.[4] Just *one percent* of the enrichment capacity required by the global growth scenario would be enough to supply the highly-enriched uranium for nearly 210 nuclear weapons every year. Reprocessing the spent fuel would add significantly to these security risks (see below).

Proposals to reduce the risks of nuclear weapons proliferation are unlikely to be successful in a world where the five acknowledged

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EDITORIAL

The return of the nuclear messiahs

ARJUN MAKHIJANI[1]

Uranium enrichment and reprocessing, once terms reserved for eggheads dealing in nuclear esoterica, are in the headlines everyday. Politicians and diplomats argue about them and the proliferation threats arising from the spread of commercial nuclear power technology.

Yet, strangely, in a parallel universe also being played out on the public stage, is the nuclear industry's claim, amplified by the megaphones of the media, that nuclear power can play a vital role in saving the Earth from another peril—severe climate disruption caused by the anthropogenic emissions of greenhouse gases.

Could it? Could nuclear power really help save the world from what is arguably the worst environmental scourge ever to confront humanity? History would suggest two things: caution about the nuclear industry's messianic proclamations and careful analysis of the problem.

The early promises of the fervent advocates of nuclear energy were of an economic paradise that nuclear energy would usher in for everyone from the needy to the greedy. No whim or need would go unfulfilled. But it was mainly fantasy and propaganda.

Almost two decades ago, browsing through the stacks of a well-endowed library, I ran into a 1950 article written by a research engineer by the name of Ward Davidson from Consolidated Edison Company of New York. It was published in *Atomics*, a nuclear industry journal of the time. Updating an earlier 1947 opinion, he wrote that the technical problems facing nuclear power were even more daunting than he had imagined. For example, the materials requirements would be stringent, given the high temperatures and damage from high neutron fluxes. Testing of the alloys to ensure the quality and uniformity needed would be difficult. All this meant, of course, that nuclear power would be quite expensive.

Reading that prescient 1950 assessment was an eye opener. Like almost everyone else, I believed that the common technical conclusion prevalent in nuclear circles in the 1940s and 1950s was that the nuclear energy would soon be "too cheap to meter." After all, that statement was made in 1954 by Lewis Strauss, Chairman of the U.S. Atomic Energy Commission (AEC), and endlessly repeated. I had presumed that Strauss and others who believed that nuclear power would be very cheap simply made a mistake. The discovery of the Davidson paper was the first inkling I had of what further research would decisively prove: it was the uniform conclusion of all serious analyses at the time that nuclear electricity would be expensive.

"Too cheap to meter" was part self-delusion, as shown by the florid and fantastic statements made by the most serious people such as Glenn Seaborg, who led the team that first isolated plutonium, and Robert Hutchins, the President of the University of Chicago during the Manhattan Project. And it was part organized propaganda designed to hide the horror of the hydrogen bomb.

> The early promises of the fervent advocates of nuclear energy were mainly fantasy and propaganda.

In September of 1953, less than a month after the detonation of the Soviet's first hydrogen bomb, AEC Commissioner Thomas Murray wrote to the commission's chairman that the United States could derive "propaganda capital" from a publicity campaign surrounding their recent decision to construct the Shippingport nuclear power plant. Sterling Cole, the chairman of the Joint Committee on Atomic Energy in the U.S. Congress, worried that the Soviets might beat the United States to a functional nuclear power plant, and thus steal the claim to being the true promoters of the "peaceful" atom. In a letter to a fellow Congressman, Sterling Cole wrote:

> It is possible that the relations of the United States with every other country in the world could be seriously damaged if Russia were to build an atomic power plant for peacetime use ahead of us. The possibility that Russia might actually demonstrate her "peaceful" intentions in the field of atomic energy while we are still concentrating on atomic weapons could be a major blow to our position in the world.[2]

As early as 1948, the Atomic Energy Commission reported to Congress that "the cost of a nuclear-fuel power plant will be substantially greater than that of a coal-burning plant of similar capacity."[3] One of the most direct of the early critiques of the economics of nuclear power came in a December 1950 speech before the American Association for the Advancement of Science by C.G. Suits. At the time, Suits was the Vice President and Director of Research at General Electric which was then operating the Hanford plutonium production reactors in Washington State and was one of the principal companies developing nuclear reactors for the production of electricity. In his speech, which was reprinted in the industry journal *Nucleonics* (Vol. 8 No. 2, February 1951), Suits stated bluntly that:

> It is safe to say… that atomic power is not the means by which man will for the first time emancipate him-

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> self economically, whatever that may mean; or forever throw off his mantle of toil, whatever that may mean. Loud guffaws could be heard from some of the laboratories working on this problem if anyone should in an unfortunate moment refer to the atom as the means for throwing off man's mantle of toil. It is certainly not that!
>
> …
>
> …The economics of atomic power are not attractive at present, nor are they likely to be for a long time in the future. This is expensive power, not cheap power as the public has been led to believe.

Now, over half a century after the fantasies and the propaganda, and over a quarter of a century since the last reactor order in the United States, the nuclear industry is returning. Then it was the promise of an endless supply of fuel—what Alvin Weinberg, the first Director of Oak Ridge National Laboratory called a "magical" energy source. Uranium-238, not a reactor fuel, would be turned into fuel in breeder reactors, even as those same reactors consumed plutonium fuel. The net result would be more fuel at the end of the cycle. With supplies of uranium-238 being rather vast, the physics of the fantasy was only slightly exaggerated.

But physics is not enough. An energy source must still meet the tests of safety, reliability, and cost. In the case of nuclear energy, there is also the unique problem of nuclear proliferation, in part hidden in the form of the plutonium content of the spent fuel and in part in the form of the spread of know-how. Taken together, these factors made the physics "magic" evaporate the first time around. Breeder reactors and the associated reprocessing have yet to be commercialized after more than $100 billion in expenditures worldwide (constant 1996 dollars) and more than fifty years of effort.

Plutonium accounting to ensure that some of it is not being diverted for weapons use has always been very difficult. Dr. Smith's book, *Insurmountable Risks*, summarized in the cover article, gives examples of this in the commercial sector. But even in the military sector at the oldest and most storied laboratory in the history of nuclear weapons, Los Alamos National Laboratory, the accounts for plutonium discharged to waste are rather a mess, as the article on page 10 shows.

It is the same today. The carbon dioxide emissions from a nuclear electricity system can be kept very small, in fact, an all-nuclear energy system could theoretically reduce them to zero. But the physics is not the problem now; nor was it then.

The problems are:

1. How much will nuclear energy cost relative to other means of getting rid of carbon dioxide emissions?
2. What kinds of subsides will be required, given that Wall Street is skittish about nuclear power?
3. What will be the risks of catastrophic accidents if we build reactors at the rate of one a week or more, cookie-cutter style, around the world?
4. What will happen to the security of power supply in case of terrorist attacks or disastrous accidents on the scale of Chernobyl?
5. What about all the plutonium in the waste?

In *Insurmountable Risks*, Brice Smith carefully analyzes all these questions and more. It is a meticulously researched work that points to the great dangers of attempting to solve the problem of reducing carbon dioxide emissions by resorting to large-scale use of nuclear energy. Were there no alternative, the severity of the threat facing humankind and other species as well from global climate change might well warrant serious consideration of the risks of nuclear energy. But we do have alternatives that will not leave proliferation headaches and risks of radioactive landscapes like the ghostly zone around Chernobyl to future generations.

> The transition to a world of a secure, carbon-emission-free energy system will be complicated and difficult.

Not that these alternatives are without risk. Some, such as carbon sequestration or LNG (liquid natural gas) terminals, carry significant risk. The transition from where we are today to a world of a secure, carbon-emission-free energy system will be complicated and difficult.

In much the same way that a cancer patient may choose to temporarily undergo chemotherapy despite its toxic side effects, we will have to make difficult choices over the coming decades to avoid the potentially catastrophic consequences of global warming. In making those choices, putting the smallest burden on future generations must surely be one of the main criteria. Nuclear does exactly the opposite—it shifts the main burdens into the future.

The idea that nuclear energy is going to save us from global climate change is becoming as fashionable today as the paeans to nuclear power as a magical energy source were half a century ago. Before buying into the nuclear establishments, read Brice Smith's book. And then work for the alternatives.

1 This editorial is mainly derived from Arjun Makhijani's Foreword to Brice Smith's book, *Insurmountable Risks* (IEER Press, 2006), and is largely based on Part I of Makhijani and Saleska, *Nuclear Power Deception* (Apex Press, 1999). References made in this editorial can be found in either book. The books are available for purchase at www.EggheadBooks.com.

2 Sterling Cole, Letter to Congressman John Phillips, May 20, 1953, with cover note from AEC secretary Roy Snapp, July 9, 1953. DOE Archives, Box 1290, Folder 2.

3 Atomic Energy Commission, "Report to the U.S. Congress, No. 4," Washington, DC, 1948.

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nuclear weapons states seek to retain their arsenals indefinitely. The institutionalization of a system in which some states are allowed to possess nuclear weapons while dictating intrusive inspections and restricting what activities other states may pursue is not likely to be sustainable. As summarized by Mohamed ElBaradei, director general of the International Atomic Energy Agency:

> We must abandon the unworkable notion that it is morally reprehensible for some countries to pursue weapons of mass destruction yet morally acceptable for others to rely on them for security—indeed to continue to refine their capacities and postulate plans for their use.[5]

Without a concrete, verifiable program to irreversibly eliminate the tens of thousands of existing nuclear weapons, no nonproliferation strategy is likely to be successful no matter how strong.

Safety

The potential for a catastrophic reactor accident or well coordinated terrorist attack to release a large amount of radiation is another unique danger of nuclear power. Such a release could have extremely severe consequences for human health and the environment. The so-called CRAC-2 study conducted by Sandia National Laboratories estimated that a worst case accident at an existing nuclear plant in the United States could, for some sites, result in tens of thousands of prompt and long-term deaths and cause hundreds of billions of dollars in damages.[6] Even if a reactor's secondary containment was not breached, a serious accident would still cost a great deal. As summarized by Peter Bradford, a former commissioner of the U.S. Nuclear Regulatory Commission (NRC):

> The abiding lesson that Three Mile Island taught Wall Street was that a group of N.R.C.-licensed reactor operators, as good as any others, could turn a $2 billion asset into a $1 billion cleanup job in about 90 minutes.[7]

Despite the importance of reactor safety, the probabilistic risk assessments used to estimate the likelihood of accidents have numerous methodological weaknesses that limit their usefulness. First, the questions of completeness and how to incorporate design defects are particularly difficult to handle. Second, concerns arise due to the fact that nuclear power demands an extremely high level of competence at all times from the regulators and managers all the way through to the operators and maintenance crews. Finally, the increased use of computers and digital systems create important safety tradeoffs, with improvements possible during normal operation, but with the potential for unexpected problems to arise during accidents. In light of the uncertainties inherent in risk assessments, William Ruckelshaus, the head of the U.S. Environmental Protection Agency under both Presidents Nixon and Reagan cautioned that:

> We should remember that risk assessment data can be like the captured spy: if you torture it long enough, it will tell you anything you want to know.[8]

"[R]isk assessment data can be like the captured spy: if you torture it long enough, it will tell you anything you want to know."
—William Ruckelshaus

In the nearly 3,000 reactor-years of experience at power plants in the United States, there has been one partial core meltdown and a number of near misses and close calls. From this, the probability of such an accident occurring is estimated to be between 1 in 8,440 and 1 in 630 per year.[9] Using the median accident probability of 1 in 1,800 per year, and retaining the assumption from the MIT report that future plants will be ten times safer than those in operation today, we find that the probability of at least one accident occurring somewhere in the world by 2050 would be greater than 75 percent for the global growth scenario, and over 90 percent for the steady-state growth scenario.

The possibility that public opinion could turn sharply against the widespread use of nuclear power following an accident is a significant vulnerability. If nuclear power was in the process of being expanded, public pressure following an accident would leave open few options. On the other hand, if long-term plans to phase out nuclear power were already being carried out, there would be far more options available and those options could be

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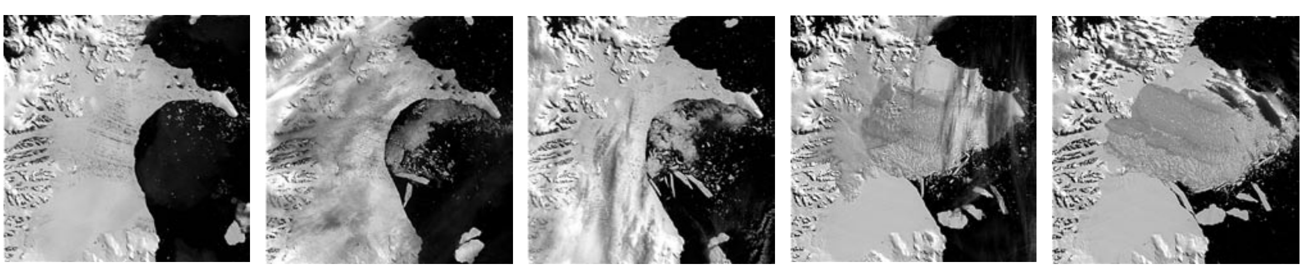

Collapse of the Larsen B ice shelf, Antarctic Peninsula. *Scientists expected the Rhode Island-sized ice shelf to retreat eventually, but were surprised it broke up in only 35 days. Over the last 50 years, the Antarctic Peninsula has warmed by 2.5°C (4.5°F), five times higher than the rest of the world. (Images courtesy Ted Scambos, National Snow and Ice Data Center, http://earthobservatory.nasa.gov/Study/LarsenIceShelf/)*

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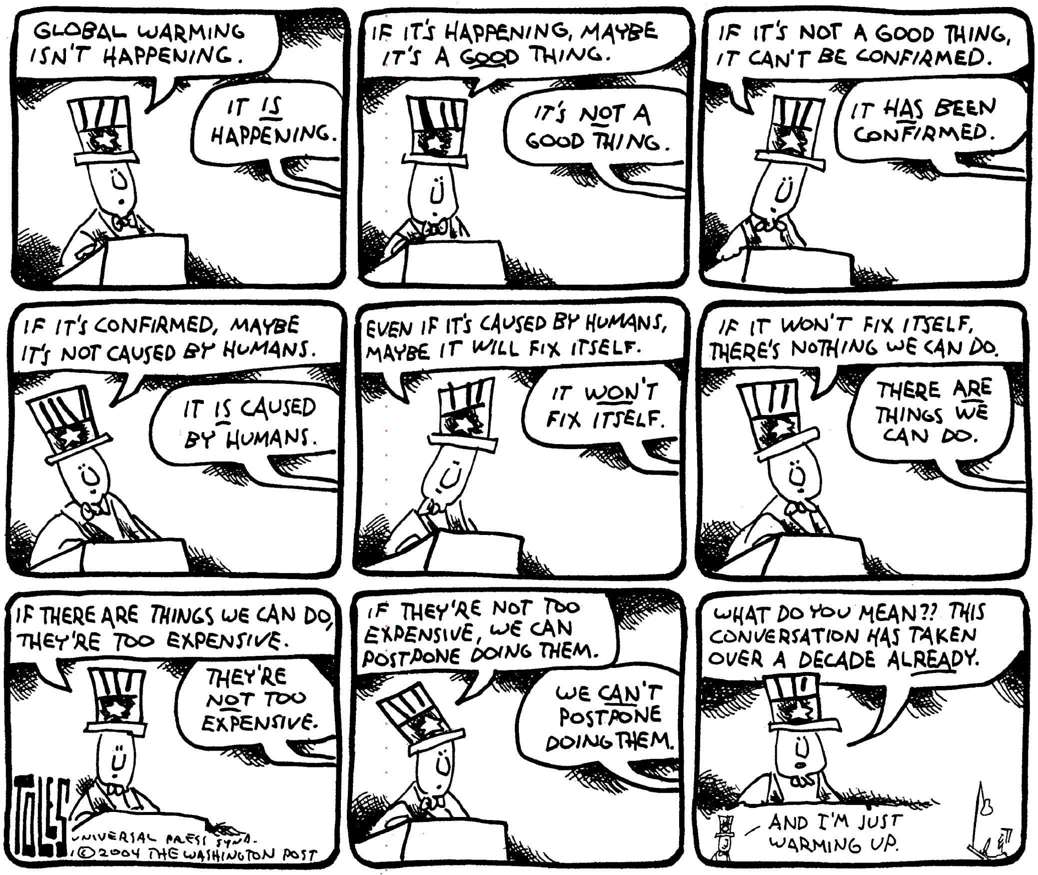
accelerated with less disruption to the overall economy.



Spent fuel

There is also the difficulty of managing radioactive waste. The existence of weapons-usable plutonium in the waste complicates the problem. While the management of low-level waste will continue to pose a challenge, by far the largest concern is how to handle spent nuclear fuel. Complicating this task are the long half-lives of some of the radionuclides present in the waste (for example: plutonium-239, half-life 24,000 years; technetium-99, half-life 212,000 years; and iodine-129, half-life 15.7 million years).

Through 2050, the global growth scenario would lead to nearly a doubling of the average rate at which spent fuel is generated, with proportionally larger increases under the steady-state growth scenario. Assuming a constant rate of growth, a repository with the capacity of Yucca Mountain (70,000 metric tons) would have to come online somewhere in the world every five and a half years in order to handle the waste that would be generated under the global growth scenario. For the steady-state growth scenario, a new repository would be needed every three years on average.

The characterization and siting of repositories rapidly enough to handle this waste would be a very serious challenge. Yucca Mountain has been studied for more than two decades, and it has been the sole focus of the U.S. Department of Energy (DOE) repository program since 1987. Despite this effort, and nearly $9 billion in expenditures, to date no license application has yet been filed. In fact, in February 2006, Secretary of Energy Samuel Bodman admitted that the DOE can no longer make an official estimate for when Yucca Mountain might open due to ongoing difficulties faced by the project.

Internationally, no country plans to have a repository in operation before 2020, at the earliest, and all repository programs have encountered problems during development. Even if the capacity per repository is increased, deep geologic disposal will remain a major vulnerability of a much-expanded nuclear power system.

> Reprocessing is expensive, adds to proliferation risks, and still generates large volumes of waste requiring repository disposal.

Alternatives to repository disposal are unlikely to overcome the challenges posed by the amount of waste that would be generated under the global or steady-state growth scenarios. Proposals to reprocess the spent fuel would not only *not* solve the waste problem, but would greatly increase the dangers. Reprocessing schemes are expensive and create a number of serious environmental risks while still generating large volumes of waste destined for repository disposal. In addition, reprocessing results in the separation of weapons-useable plutonium, adding significantly to the risks of proliferation. While future reprocessing technologies like UREX+ or pyroprocessing could have some nonproliferation benefits, they would still pose a significant risk if deployed on a large scale. Under the global growth scenario, the authors of the MIT study estimate that more than 155 metric tons of separated plutonium would be required annually to supply the required MOX (mixed-oxide)

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fuel. Just *one percent* of this commercial plutonium would be sufficient to produce more than 190 nuclear weapons every year.

The authors of the MIT study acknowledge the high cost and negative impacts of reprocessing and, as such, advocate against its use. Instead they propose interim storage and expanded research on deep borehole disposal. It is possible that deep boreholes might prove to be an alternative in countries with smaller amounts of waste. However, committing to a large increase in the rate of waste generation based only on the potential plausibility of a future waste management option would be to repeat the central error of nuclear power's past. The concept for mined geologic repositories dates back to at least 1957. However, turning this idea into a reality has proven quite difficult, and not one spent fuel rod has yet been permanently disposed of anywhere in the world.

Costs

Nuclear power is likely to be an expensive source of electricity, with projected costs in the range of six to seven cents per kilowatt-hour (kWh) for new reactors. Tables 1 and 2 show data from the MIT study and a study conducted at the University of Chicago.[10] Table 1 shows estimates used for the projected capital costs, construction lead times and interest rate for natural gas, coal and nuclear power in the United States. Table 2 show estimates of cost per kilowatt-hour.

While a number of potential cost reductions have been considered by nuclear power proponents in the United States, it is unlikely that plants not heavily subsidized by the federal government would be able to achieve these. This is particularly true given that the cost improvements would have to be maintained under the very demanding timetables set by the global or steady-state growth scenario.

Promising alternatives

A number of energy alternatives that are economically competitive with new nuclear power are available in the near to medium term.[11] The choice between these alternatives will hinge primarily on the rapidity with which they can be brought online and on their relative environmental and security impacts.

Of the available near-term options for reducing greenhouse gas emissions, the two most promising ones in the United States and other areas of the Global North are increasing efficiency and expanding the use of wind power at favorable sites. At approximately four to six

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TABLE 1: COMPARISON OF SOME ASSUMPTIONS USED IN THE MIT AND UNIVERSITY OF CHICAGO STUDIES

Generation Type	MIT Study (2003)			University of Chicago Study (2004)		
	Overnight Capital Cost ($ per kW)	Lead Time for Construction (years)	Effective Interest Rate	Overnight Capital Cost ($ per kW)	Lead Time for Construction (years)	Effective Interest Rate
Natural Gas	500	2	9.6%	500 to 700	3	9.5%
Coal	1,300	4	9.6%	1,182 to 1,430	4	9.5%
Nuclear	2,000	5	11.5%	1,200 to 1,800	7	12.5%

TABLE 2: LEVELIZED COST OF ELECTRICITY ESTIMATED BY THE MIT AND UNIVERSITY OF CHICAGO STUDIES

Generation Type	MIT Report (2003)	University of Chicago Report (2004)
Coal[a]	4.2 cents per kWh	3.3 to 4.1 cents per kWh
Natural Gas (CCGT)[b]	3.8 to 5.6 cents per kWh	3.5 to 4.5 cents per kWh
Nuclear Power[c]	6.7 cents per kWh	6.2 cents per kWh

a These estimates are for pulverized coal fired plants. Levelized cost of coal in the MIT study is $1.30 per million Btu (MMBtu) while the average price of coal in the U Chicago study is $1.02 to $1.23 per MMBtu.

b These estimates are for combined cycle gas technology (CCGT) natural gas plants. Levelized cost of natural gas in the MIT study is $3.77 to $6.72 per MMBtu. The average price of natural gas in the U Chicago study is $3.39 to $4.46 per MMBtu. The recent price for natural gas has been well above the "high" fuel price used in these studies. However, long-term gas prices can be expected to remain within the range of costs assumed by the MIT study if policies on efficiency, conservation, and an increased reliance on liquefied natural gas are pursued.

c Overnight capital cost of a nuclear plant in the MIT study is $2,000 per kW. While the U Chicago analysis considered a range of capital costs from $1,200 to $1,800 per kW, the lower end of this range was so far out of what could be reasonably expected from experience in the United States and around the world that it is not a credible basis for analysis. The middle of the U Chicago range, $1,500 per kW, was used in this analysis.

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cents per kWh, wind power at favorable sites in the United States is already competitive with natural gas or new nuclear power. With the proper priorities on upgrading the transmission and distribution infrastructure and changing the way the electricity sector is regulated, wind power could expand rapidly in the United States. In fact, without any major changes to the existing grid, wind power could expand to 15 to 20 percent of U.S. electricity supply, as compared to less than one-half of one percent in 2003, without negatively impacting overall stability or reliability.

Improvements in energy efficiency could continue to be made in the medium term as well. For example, as the current building stock turns over, older buildings could be replaced by more efficient designs. In addition, the utilization of wind power, thin-film solar cells, advanced hydropower at existing dams, and some types of sustainable biomass could allow renewables to make up an increasingly significant proportion of the electricity supply over the medium term. This expansion of renewables could be facilitated through the development of a robust mix of technologies, the development of strengthened regional grids to help stabilize the contribution of wind and solar power through geographic distribution, the use of pumped hydropower systems to store excess electricity during times of low demand, and the tighter integration of large scale wind farms with natural gas fired capacity. [12]

While it would require a significant effort to implement new efficiency programs and to develop the necessary infrastructure to expand wind power, these efforts must be compared to the difficulties that would be encountered in restarting a nuclear power industry that hasn't had a new order placed in the United States in more than 25 years and hasn't opened a single new plant in the last ten years. In addition, the current fossil fuel based energy system is very expensive to maintain. For example, the International Energy Agency estimates that the amount of investment in oil and gas between 2001 and 2030 will total nearly $6.1 trillion, with 72 percent of that going towards new exploration and development efforts.

Transition technologies

Energy efficiency and renewable energy programs have few negative environmental or security impacts compared to our present energy system and, in fact, have many advantages. As a result, these options should be pursued to the maximum extent possible. However, in order to stabilize the climate, it appears likely that some energy sources with more significant tradeoffs will also be needed as transition technologies.

The two most important transition strategies are increased reliance on the import of liquefied natural gas (LNG) and the development of integrated coal gasification plants (IGCC—integrated gasification combined cycle) with sequestration of the carbon dioxide emissions in geologic formations.

> In order to stabilize the climate, some energy sources with more significant tradeoffs will be needed as transition technologies.

Compared to pulverized coal plants, combined cycle natural gas plants emit about 55 percent less CO_2 for the same amount of generation. If efficiency improvements and an expanded liquidification and regasification infrastructure can stabilize the long-term price of natural gas at the cost of imported LNG, then the use of combined cycle natural gas plants is likely to remain an economically viable choice for replacing highly inefficient coal fired plants.

The use of coal gasification technologies would greatly reduce the emissions of mercury, particulates, and sulfur and nitrogen oxides from the burning of coal. However, for coal gasification to be considered as a potentially viable transition technology, it must be accompanied by carbon sequestration, the injection and storage of CO_2 into geologic formations. Experience in the United States with carbon dioxide injection as part of enhanced oil recovery has been gained since at least 1972. In addition, the feasibility of sequestering carbon dioxide has been demonstrated at both the Sleipner gas fields in the North Sea and the In Salah natural gas fields in Algeria. While the costs of such strategies are more uncertain than those of other mitigation options, estimates for the cost of electricity from power plants with carbon sequestration still fall within the range of six to seven cents per kWh.

> No energy system is free of negative impacts. The challenge is to choose the least bad mix of options.

Some of the most troubling aspects of coal, such as mountain top removal mining, would be mitigated by the reduction in demand due to increased efficiency and the rapid expansion of alternative energy sources. In addition, it appears likely that coal gasification and carbon sequestration would be better suited to the Western United States given the greater access to oil and gas fields which have already been explored and which offer the potential for added economic benefits from enhanced oil and gas recovery. On the other hand, the Eastern United States would appear better suited for an expanded use of LNG during the transition given the existing regasification capacity, the well developed distribution system, and the shorter transportation routes from the Caribbean, Venezuela, and Western Africa.

The continued use of fossil fuels during the transition period will have many serious drawbacks. However,

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these must be weighed against the potentially catastrophic damage that could result from global warming and against the unique dangers that accompany the use of nuclear power. To trade one uncertain but potentially catastrophic health, environmental and security threat for another is not a sensible basis for an energy policy.

No energy system is free of negative impacts. The challenge is to choose the least bad mix of options in the near to medium term while achieving significant global reductions in CO_2 emissions, and to move long term toward the development of a sustainable and equitable global energy system.

Conclusion

Just as the claim by Atomic Energy Commission Chairman Lewis Strauss that nuclear power would one day be "too cheap to meter" was known to be a myth well before ground was broken on the first civilian reactor in the United States, and just as the link between the nuclear fuel cycle and the potential to manufacture nuclear weapons was widely acknowledged before President Eisenhower first voiced his vision for the "Atoms-for-Peace" program, a careful examination today reveals that the expense and vulnerabilities associated with nuclear power would make it a risky and unsustainable option for reducing greenhouse gas emissions.

As the authors of the MIT report themselves conclude:

> The potential impact on the public from safety or waste management failure and the link to nuclear explosives technology are unique to nuclear energy among energy supply options. *These characteristics and the fact that nuclear is more costly, make it impossible today to make a credible case for the immediate expanded use of nuclear power.*[13]

Nuclear power is a uniquely dangerous source of electricity that would create a number of serious risks if employed on a large scale. It is very unlikely that the problems with nuclear power could be successfully overcome given the large number of reactors required for even modestly affecting carbon dioxide emissions. It has now been more than 50 years since the birth of the civilian nuclear industry and more than 25 years since the last reactor order was placed in the United States.

It is time to move on from considering the nuclear option and to begin focusing on developing more rapid, robust and sustainable options for addressing the most pressing environmental concern of our day. The alternatives are available if the public and their decision makers have the will to make them a reality. If not, our children and grandchildren will have to live with the consequences.

1 This article is based on *Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change* by Brice Smith (IEER Press, 2006). Full references can be found in the book, which is available for purchase at www.EggheadBooks.com.

2 See Paul J. Meier, "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis", Ph.D. Dissertation, University of Wisconsin-Madison, August 2002, online at http://fti.neep.wisc.edu/pdf/fdm1181.pdf; and, Uwe R. Fritsche, *Comparison of Greenhouse-Gas Emissions and Abatement Cost of Nuclear and Alternative Energy Options from a Life-Cycle Perspective, Updated Version* (Öko-Institut, Darmstadt, January 2006).

3 John Deutch and Ernest J. Moniz (co-chairs) et al., *The Future of Nuclear Power*, An Interdisciplinary MIT Study, 2003, online at http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf.

4 A typical 1000 megawatt (MW) light-water reactor requires approximately 100 to 120 MTSWU per year in enrichment services to provide its fuel. For simplicity in this calculation we have assumed 110 MTSWU per year would be required for future reactors. (MTSWU stands for metric ton separative work unit, a complex unit that essentially represents the amount of effort required to achieve a given level of enrichment.)

5 Mohamed El Baradei, "Saving Ourselves from Self-Destruction", *New York Times*, February 12, 2004.

6 Jim Riccio, *Risky Business: The Probability and Consequences of a Nuclear Accident*, A Study for Greenpeace USA, 2001, online at www.greenpeace.org/raw/content/usa/press/reports/risky-business-the-probabilit.pdf.

7 Matthew Wald, "Interest in Building Reactors, but Industry Is Still Cautious," *New York Times*, May 2, 2005.

8 William D. Ruckelshaus, "Risk in a Free Society", *Risk Analysis*, Vol. 4 No. 3, 157–162 (1984), pp. 157–158.

9 The cited range represents our estimate for the 5-95 percent confidence interval for the average accident rate (i.e. there is a 5 percent chance that the actual accident rate is greater than 1 in 633 per year and a 5 percent chance that it is less than 1 in 8,440 per year.)

10 *The Economic Future of Nuclear Power*, A Study Conducted at The University of Chicago, August 2004.

11 The importance of the fact that the cost of all of the alternatives tend to cluster around six to seven cents per kWh was originally noted by Dr. Arjun Makhijani.

12 Dr. Arjun Makhijani has long advocated for changes to the U.S. energy system. For a discussion of the IEER recommendations put forth by Dr. Makhijani for how to best facilitate the expansion of energy efficiency programs and the development of renewable energy resources, including actions at the state and local level, see: pp. 181–195 of Arjun Makhijani and Scott Saleska, *The Nuclear Power Deception* (Apex Press, New York, 1999); pp. 48–57 of Arjun Makhijani, *Securing the Energy Future of the United States: Oil, Nuclear, and Electricity Vulnerabilities and a post-September 11, 2001 Roadmap for Action*, November 2001; and, pp. 7–10 of Arjun Makhijani, Peter Bickel, Aiyou Chen, and Brice Smith, *Cash Crop on the Wind Farm: A New Mexico Case Study of the Cost, Price, and Value of Wind-Generated Electricity*, Prepared for presentation at the North American Energy Summit Western Governors' Association, Albuquerque, New Mexico, April 15–16, 2004. All are available at www.ieer.org.

13 Deutch and Moniz, op. cit., p. 22 (emphasis added).

Dangerous Discrepancies

Missing Plutonium in the U.S. Nuclear Weapons Complex?

BY ARJUN MAKHIJANI[1]

In 1996, the U.S. Department of Energy (DOE) published an historical report on weapons plutonium, often called the "50 Years Report" because it contained data on the first fifty years of plutonium production in the United States. The report also contained details on the inventories of plutonium at various DOE sites around the country. As part of the preparation of this historic document, which was part of the Openness Initiative of then Energy Secretary Hazel O'Leary, the DOE also made an effort to assess how much plutonium was contained in waste generated in the course of producing and processing plutonium since the inception of the nuclear weapons complex during the Manhattan Project.

In the course of compiling the data, the DOE found that the plutonium inventories in waste that were part of the materials accounting documentation at DOE Headquarters did not match the plutonium inventories in waste generated by DOE Operations Offices (the sites). The discrepancies were large in some cases, with Los Alamos National Laboratory (hereafter Los Alamos or LANL or the lab) having the largest discrepancy by far. An internal memorandum prepared for Secretary O'Leary indicated a discrepancy at Los Alamos as large as 765 kilograms—enough to make about 150 nuclear bombs.[2]

The Institute for Energy and Environmental Research (IEER) tried for years to get the DOE and Los Alamos to address the discrepancy, only to be rebuffed by public relations comments.[3] IEER therefore undertook its own detailed analysis of plutonium in waste at Los Alamos, on which this article is based.

Note that the discrepancies discussed here are not the problems that go under the general rubric of "Material Unaccounted For" (MUF), or another term for the same thing, "Book-Physical Inventory Differences" (B-PID). MUF and B-PID related inventory differences arise from factors such as measurement errors and unanticipated holdup of material in processing areas. This analysis does not deal with such inventory differences. Rather, this article and the report it is based on are about discrepancies between two sets of accounts relating to how much plutonium is in waste. In effect, we are dealing with two sets of books on a part of the plutonium accounting system.

Our central finding is that, according to official records, the discrepancy amounts to about 300 kilograms, enough to make about 60 nuclear bombs. The materials security account for plutonium at Los Alamos states that the lab created waste containing 610 kilograms of plutonium. This account is called the Nuclear Materials Management Safeguards System (NMMSS). But when all the waste accounts are added up, the total is just over 300 kilograms.

These data give rise to some questions:

- What happened to the other 300 or so kilograms of plutonium in the waste that the NMMSS account states was sent out in the waste but is not shown in the waste accounts?
- Was it dumped somewhere onsite in the early decades of production but the waste accounts do not show it?
- Is it stored in the barrels of waste that have been sent or will be sent to the deep geologic repository in New Mexico, known as the Waste Isolation Pilot Plant?
- Or is the NMMSS account wrong, and less waste was actually generated than was reported?

If the last is true, it would have the gravest security implications, because it could mean that plutonium stated to be in waste in the master security account may actually have been diverted for unauthorized purposes.

> Our central finding is that the discrepancy amounts to about 300 kilograms, enough to make about 60 nuclear bombs.

The discrepancy remains unexplained. The potential environmental, health, and security implications of such a large plutonium discrepancy are serious.

It is noteworthy in this context that the International Atomic Energy Agency has held Japan to a very strict standard of accountability for plutonium account discrepancies amounting to about 200 kilograms. Japan has had to undergo inspections and explanations of its plutonium facilities as a result of the discrepancies. But the United States, because it is a nuclear weapon state, is exempt from any international accountability in the weapons arena, despite the obvious global non-proliferation implications of its own plutonium account discrepancies.

For some perspective, 300 kilograms is roughly seven times the amount of plutonium that North Korea is supposed to possess that has rightly been the object of immense concern to the United States and other countries, as well as the International Atomic Energy Agency.[4]

Nuclear materials accounting

Figure 1 shows a schematic diagram of nuclear materials accounting, in this case of weapons plutonium account-

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ing. Overall, the material that comes into a facility (M) should equal the amount shipped out as finished product (P) plus the amount sent out of secure processing areas in waste (W) plus the change in inventory at the facility (ΔI). Any discrepancy between the amount entering the facility and the other aggregate quantities should be to within measurement errors.

For each of the accounting quantities (input, product, waste, inventory change) there should be one number for each of the quantities. But the DOE has two numbers for plutonium in waste (W):

1. One is the amount of plutonium in waste as stated in the materials accounting system inside a security perimeter where plutonium in weapons-usable form is received, held, processed, and shipped. This accounting system is officially called the Nuclear Materials Management Safeguards System (NMMSS). It represents the master account of nuclear materials, including plutonium in waste, to ensure that none is diverted in unauthorized ways.
2. The other number is the amount of plutonium in waste as stated by LANL's waste management organization to which the waste containing plutonium is sent from the secure processing and storage areas. Waste is sent outside the secure perimeters when the weapons plutonium is diluted to such a degree that it can no longer be easily extracted and purified for use in weapons. We will call this the waste management account.

The amount of plutonium in these two accounts should match. That is, the amount of plutonium entered into the NMMSS account as waste should be the same as that believed to be held by the waste management

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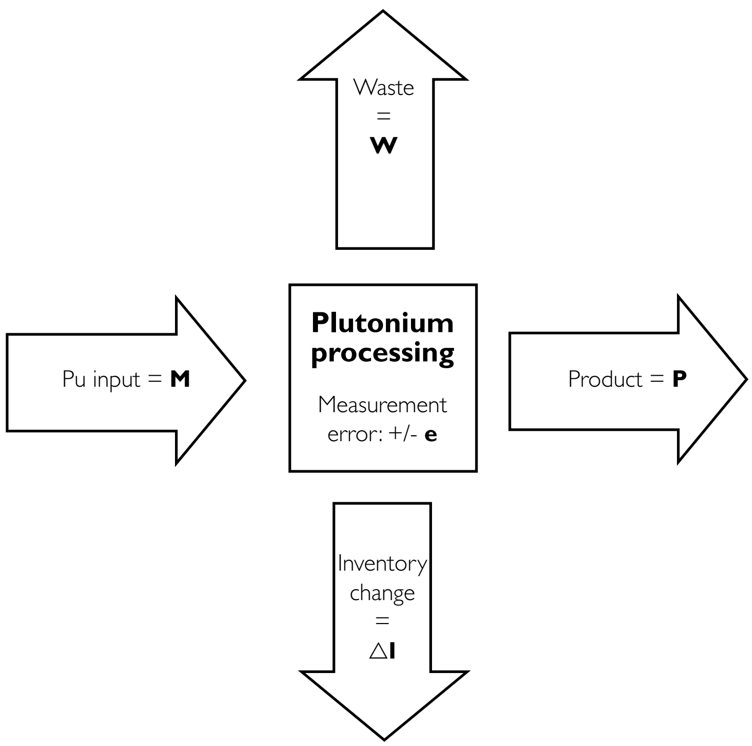
FIGURE 1: SIMPLIFIED FLOWCHART SHOWING MATERIALS ACCOUNTING PARAMETERS



Material balance equation: M = P + W +△I +/- e

M is the book value of plutonium received. P is the measured value of the output. W is the measured value of the Pu in waste. ΔI is the change in the inventory at the facility. The two sides of the equation should match up to within the measurement error "e" (at a certain confidence level, 99 percent for instance).

The discrepancy discussed in this article is between two values of plutonium in waste (W): that in the security account and the sum of the values in all the waste accounts. These should match. But for Los Alamos they do not, indicating that one or both numbers are wrong.

Having two sets of books for plutonium in waste is much like having two sets of books for accounting for petty cash at a branch office — one for reporting to headquarters (like the NMMSS account of plutonium in waste), and one for managing it internally at the branch (like the various waste management accounts of plutonium in waste). If the books do not match closely, it indicates that money was spent but has not been accounted for, or that money was reported as spent but actually was illegally diverted, or both. Either way it spells trouble — or should.

TABLE 1: PLUTONIUM-239/240 IN LOS ALAMOS WASTE ACCOUNTS AND IN THE NMMSS ACCOUNT WASTE DECLARATION, AND THE DISCREPANCY

	LANL Subsurface total	At or Bound for WIPP	Total waste accounts	NMMSS Account Waste Declaration	Discrepancy
High waste estimate	140	200	340	610	270 (low estimate)
More realistic estimate	100	200	300	610	310 (more realistic)

Note: All figures in kilograms, rounded to the nearest 10 kilograms.

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organization because the latter is the same waste as was sent out of the secure areas.

The fact that the two numbers do not match at Los Alamos (and at some other sites) caused sufficient concern inside the DOE that it established a "working group to study the different accounting methods for plutonium data, to resolve differences from these methods, and to make recommendations on the appropriateness of making changes to how the Department tracks it plutonium inventories." This indicates the seriousness with which the DOE itself viewed the discrepancies in 1996, when the plutonium inventories and accounts were made public.[5]

The working group, however, produced no public report. So far as is known, it produced no report at all. So IEER, using the most recent data compiled by the DOE, performed its own analysis.

Table 1 illustrates the discrepancy between the amounts of plutonium discharged into the waste as reported in the waste management account and that as reported in the NMMSS account. To indicate uncertainties we made two estimates, based on official data, of the amounts of plutonium in subsurface soil[6] at Los Alamos, 100 kilograms and 140 kilograms. The second column of figures in Table 1 shows the waste disposed of at the Waste Isolation Pilot Plant (WIPP) and that stored at Los Alamos for future disposal at WIPP. The total of all these items stated by various official documents to be in the waste accounts is somewhere between 300 kilograms (realistic estimate) and 340 kilograms (high estimate).

Since the NMMSS account states that 610 kilograms of plutonium was sent out of the security perimeter in waste, there is obviously a large discrepancy. The lowest estimate of this discrepancy is 270 kilograms and a more realistic estimate is about 310 kilograms. IEER's high estimate for the discrepancy is 350 kilograms.

We also examined the annual patterns of waste discharges that were logged into the NMMSS account. Facility materials accounting for security purposes (along the lines of the simplified schematic in Figure 1)

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TABLE 2: NORMAL OPERATING LOSSES OF PLUTONIUM AT LOS ALAMOS NATIONAL LABORATORY (IN KILOGRAMS)

Year	Annual Losses	Cumulative Losses
Through 1968	4.3	4.3
1969	1.3	5.6
1970	0.3	5.9
1971	0.2	6.1
1972	0.4	6.5
1973	0.7	7.2
1974	5.3	12.5
1975	5.0	17.5
1976	4.6	22.1
1977	4.2	26.3
1978	8.2	34.5
1979	13.1	47.6
1980	20.0	67.6
1981	22.1	89.7
1982	55.1	144.8
1983	69.7	214.5
1984	78.9	293.4
1985	92.4	385.8
1986	84.8	470.6
1987	24.7	495.3
1988	26.9	522.2
1989	28.8	551.0
1990	18.9	569.9
1991	2.0	571.9
1992	4.6	576.5
1993	24.9	601.4
1994	8.6	610.0

Source: U.S. Department of Energy. *Plutonium: The First 50 Years: United States Plutonium Production, Acquisition, and Utilization from 1944 to 1994*. Washington, DC: DOE, February 1996, p. 57 (Table 9). On the Web at www.fas.org/sgp/othergov/doe/pu50y.html.

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is done annually and, hence, the amounts of plutonium discharged to the waste must also be reported annually. Table 2 shows the annual plutonium discharges to waste in the NMMSS account. Note that the number in the 1968 column is an aggregate until that date.

According to the NMMSS account of plutonium in waste, reproduced in Table 2, the vast majority of plutonium, a little more than 560 kilograms out of a total of 610 kilograms, was discharged into waste streams in the 1980s and 1990s, of which more than 500 kilograms was in the 1980s alone. Transuranic waste records show that the burial of significant amounts of plutonium in waste on site stopped in 1979. The WIPP waste accounts, certified by the EPA as being sound in 2004 and again in 2005,[7] show a total of only about 200 kilograms of plutonium in waste that is stored at LANL or that has been shipped from LANL to WIPP. Hence if the NMMSS waste account of Los Alamos, shown in Table 2, is correct then the WIPP account must be wrong by a large amount, by about 360 kilograms (560 minus 200).

IEER has been assured by Ambassador Linton Brooks, the Administrator of the National Nuclear Security Administration (NNSA), which is a part of the DOE, that "the Department of Energy has the utmost confidence in the information contained in the facility accountability systems and the NMMSS."[8] At the same time, we have been assured by Bonnie Gitlin, Acting Director of the Radiation Protection Division of the U.S. Environmental Protection Agency, that the WIPP waste data meet the technical and legal specifications required for shipment to WIPP.[9] These legal and technical specifications do not allow uncertainties so large to cause, for instance, unforeseen criticality risks. Since just few kilograms of plutonium are needed to create such risks, a discrepancy of hundreds of kilograms is on its face unacceptable. But the NMMSS account clearly implies that there must be about 360 more kilograms of plutonium in WIPP waste than that shown in the WIPP data to date.

So if the NMMSS account is correct, the WIPP account must be wrong. This means that the process of characterization and certification of WIPP waste is seriously deficient since it is missing more than half of the plutonium that the NMMSS states was discharged into waste streams in the 1980s and 1990s, when this waste was almost all retrievably stored for future disposal in WIPP.

In short, there is a fundamental incompatibility between the WIPP account, which has been certified as meeting the legal and technical criteria by the EPA, and the NMMSS account, which the NNSA endorses as being completely sound. Both assertions cannot be right at the same time. Indeed, one of them must be wrong. Of course, it is possible that both are wrong.

If the WIPP account is wrong by as much as 360 kilograms, it would mean the utter failure of the certification process for transuranic waste at Los Alamos. IEER, in cooperation with the Southwest Research and Information Center, has called on the EPA to suspend further shipments from Los Alamos to WIPP until the plutonium discrepancies are satisfactorily explained. IEER has also asked the NNSA to further investigate the issue. Finally, the DOE Inspector General accepted IEER's analysis as a complaint. But it decided not to conduct a full audit and to defer to the statement of the Administrator of the National Nuclear Security Administration that the nuclear materials safeguards account is sound.

It is possible that far more waste was buried on site during the years before 1970 when waste containing significant concentrations of plutonium was packaged in rudimentary containers and dumped in pits and trenches. This was the practice all over the nuclear weapons complex at the time. The special category "transuranic waste" destined for disposal in a repository was created in the wake of the scandal caused by the large plutonium fire at Rocky Flats in 1969. (Los Alamos continued to bury transuranic waste after that date, until 1979, with the idea that it would later be retrieved; the premise turned out to be incorrect.) Official communications as well as informal opinions have tended to imply that the missing plutonium must be in the waste that was buried in the first two or three decades. However, this explanation is less than persuasive.

First of all, the estimate of cumulative plutonium in buried waste in the NMMSS account to 1979 is only 47.6 kilograms (Table 2). Second, this amount closely matches the database for transuranic wastes produced by the DOE in 1999 and 2000. The part of this database that details Los Alamos waste indicates that about 50 kilograms of plutonium was dumped in buried wastes in the period before transuranic wastes were retrievably stored. Hence, the buried waste accounts are the only ones where the waste data and security data match. This does not mean that the buried waste data are right, but it does make it unlikely that the buried waste data are very wrong.[10] Finally, if the buried waste contains as much as 360 kilograms of plutonium (the approximate amount needed to explain the discrepancy) more than is currently attributed to buried waste, it would also mean that the NMMSS account is wrong, since it only shows 47.6 kilograms in buried waste.

This reinforces the conclusion that either the WIPP account or the NMMSS account is wrong. The implications in either case are very serious. Of course, both could be wrong, in which case the implications would be even more serious.

Plutonium waste per kilogram processed

In order to get a better understanding of whether the waste accounts may be wrong, we made a comparison

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of the waste generated per kilogram of plutonium processed at Los Alamos compared to that generated by Rocky Flats operations, where about 70,000 plutonium pits were fabricated during the Cold War. This means that somewhere between 230,000 and 280,000 kilograms of plutonium were processed at Rocky Flats. The total amount of plutonium in waste generated in Rocky Flats is estimated at just under 5,600 kilograms. Hence about 2 to 2.4 percent of the plutonium processed at Rocky Flats was discharged to waste.

It is more difficult to estimate the total plutonium processed at Los Alamos. About 600 plutonium pits were fabricated there over five decades, consisting of 2,000 to 2,400 kilograms of plutonium. About 100 kilograms were used in hydronuclear and other test devices. There were a variety of other experiments and activities involving plutonium at Los Alamos, but these quantities usually were very small. In view of this, about 3,000 kilograms of plutonium appears to be a reasonable value for plutonium processed at Los Alamos.

If the 3,000-kilogram figure for plutonium processed into devices at Los Alamos is taken as being near the correct figure, then 610 kilograms of plutonium in the waste would mean that, on average, about 20 percent of the amount of plutonium processed at Los Alamos wound up in waste. In other words, Los Alamos wasted eight to ten times as much plutonium as Rocky Flats per unit of plutonium processed. Given the distribution of waste over the decades, the figure in the 1980s was likely to have been considerably higher.

It is possible that there were activities at Los Alamos in the 1980s that involved processing large amounts of plutonium that were not captured in the 3,000-kilogram estimate described above. However, if the waste generation was comparable in percentage to Rocky Flats, the total amount of plutonium processed in the 1980s would be in the range of about 20,000 to 25,000 kilograms. While this is possible, it seems rather unlikely. If the NMMSS account is correct, hundreds of millions of dollars of plutonium were sent to waste in the 1980s at rates of wastage per unit of production that were likely to have been much larger than Rocky Flats.

MAIN FINDINGS

1. There are major discrepancies in the materials accounts for weapons plutonium in waste at the Los Alamos National Laboratory (LANL). An analysis of official data indicates that the unaccounted-for plutonium amounts to about 300 kilograms, enough to make about 60 nuclear bombs. It is not known whether the plutonium was buried as waste, sent to the Waste Isolation Pilot Plant (WIPP), or diverted.
2. If much or most of the plutonium was disposed of as buried low-level waste, the annual reports of plutonium lost to waste in the security account (the NMMSS account), are wrong.
3. If the missing plutonium is actually in the waste that is stored and destined to be sent to WIPP, or already at WIPP, then the WIPP waste characterization is incorrect and the certification of that waste for shipment to WIPP is seriously deficient.
4. If the WIPP accounts are correct, then the large amounts of plutonium shown as being discarded to waste in the 1980s in the NMMSS account must be wrong.
5. In view of the above, it is clear that either the WIPP estimates of plutonium in waste are wrong by about 360 kilograms or at least a part of the NMMSS account is wrong.

MAJOR RECOMMENDATIONS

1. The EPA should suspend shipments of transuranic waste from Los Alamos to WIPP until the discrepancy is satisfactorily explained.
2. The DOE Inspector General should investigate the plutonium discrepancies at the level of a full audit.
3. The NNSA and the EPA should collaboratively determine which of their waste plutonium accounts is in error and make the results of the investigation public.
4. The United States should make it a high diplomatic priority to urge other countries with undeclared stocks of highly enriched uranium and plutonium to declare them in a manner similar to that done by then U.S. Energy Secretary Hazel O'Leary. These should include estimates of plutonium discharged to solid wastes streams, to the atmosphere, and to liquid effluents.

Security implications

The analysis above raises a very distinct possibility that the NMMSS account may be wrong, notably in the 1980s. If that is the case, the security implications could be grave. The failure to maintain materials accounts for plutonium to the point that hundreds of kilograms may have been diverted would be a stunning conclusion. IEER has not arrived at this conclusion as yet. It is very possible that the WIPP account is significantly wrong and this needs to be carefully assessed. If the WIPP account is not wrong, then the NMMSS account must be wrong. In that case, a full security investigation of what happened to several hundred kilograms of plutonium that is now marked as being sent to waste would be utterly necessary.

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Conclusion

In 1996, then-Secretary of Energy Hazel O'Leary made a farsighted and courageous decision when she made public U.S. data on weapons plutonium production and storage. Had she not done that, these discrepancies never would have come to light.[11] Given the similarity in techniques and attitudes in nuclear weapons establishments on many issues, it highly unlikely that the situation in other countries is any better overall, though there may be some variations of course. The analysis in this article demonstrates that such discrepancies could have the gravest security implications unless they are investigated and explained. Assuring that the accounting for fissile materials is sound and that they have not been diverted requires comparable declarations for plutonium and highly enriched uranium from other nuclear weapon states — Russia, China, Britain, France, Israel, India, Pakistan, and North Korea.[12]

1 This article is based on *Dangerous Discrepancies: Missing Plutonium in Los Alamos National Laboratory Waste Accounts,* Institute for Energy and Environmental Research, April 21, 2006. The study was undertaken as part of a Citizens' Monitoring and Technical Assessment Fund Grant, administered by RESOLVE, Inc. References can be found in the report, which can be found online at www.ieer.org/latest/pudiscrepanciesindex.html. Details of some results presented here but not explained in detail can also be found there.

2 Guimond, R.J. and E.H. Beckner, *Memorandum on Plutonium in Waste Inventories,* U.S. Department of Energy, January 30, 1996, at www.ieer.org/offdocs/Guimond1996Memo.pdf.

3 For documentation of IEER efforts, see www.ieer.org/latest/pudiscrepanciesindex.html.

4 The most recent estimate of North Korea's plutonium stock is 40 to 55 kilograms as of mid-2005. (Institute for Science and International Security) International concerns were already high when North Korea's plutonium stock was estimated to be in the 20 to 30 kilogram range.

5 Guimond and Beckner 1996, *op. cit.*

6 Subsurface soil includes shallow land burial, deeper disposal on-site, and residues onsite from plutonium used in various kinds of tests such as hydronuclear tests, which are not full-scale nuclear explosions.

7 Bonnie Gitlin letter to Arjun Makhijani, May 2, 2006, on the Web at www.ieer.org/latest/pudiscrepanciesindex.html.

8 Linton Brooks letter to Arjun Makhijani, February 28, 2006, on the Web at www.ieer.org/latest/pudiscrepanciesindex.html.

9 Gitlin, *op. cit.*

10 Some of the unaccounted-for plutonium may also have been discharged to the air and into waste water above the amounts logged in those accounts. However, typically, solid wastes contain far more of the radioactive materials in waste than air or water. Further, the largest waste amounts in the NMMSS waste account are in the 1980s and 1990s (over 90 percent in all). The vigilance regarding water and air emissions in these years was far greater than in the pre-1970 period. Hence, air and waste water accounts are not analyzed in this report as a major explanation for the plutonium discrepancy. However, it is an aspect that needs investigation, since additional discharges into air and/or water above those reported may have implications for health, environment, cleanup, and compliance with regulations.

11 Makhijani, Hu, and Yih, eds. *Nuclear Wastelands,* MIT Press, 2000.

12 Commercial stocks are declared to the International Atomic Energy Agency.

Thank you very much.

IEER is grateful to our ***superscribers*** (donors of at least $100), ***hyperscribers*** (at least $250), and ***Dr. Egghead's Financial Angels*** ($1,000 or more). Since December 2005:

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IEER research and analyses have made important contributions to campaigns to **stop nuclear weapons** production, **improve cleanup** of nuclear weapons production sites, and get a modicum of **justice** for sick nuclear weapons workers.

Thanks also to our foundation funders, listed on page 2.

Dear Arjun

Dear Arjun,

Are you anti-nuclear or pro-nuclear?

—Wondering in Wyoming

Dear Wondering,

Long, long ago, before the age of Lemon Pledge®, Nu-Clear Wax was a magical wax that gave furniture a permanent shine. It also repelled all dust. It was so effective that the company went out of business—there were never any repeat sales. Later, the two parts of Nu-Clear were collapsed into one word, nuclear, meaning the stuff that's inside your cells (and mine). For that reason, I have always been pro-nuclear. I am especially partisan to the nuclear material in my mitochondria, all of which I got from my mother (you did too—not from my mother, but from yours).

Modern physics and the advent of the Bomb changed everything and confused the nuclear issue. Now nuclear means so many things it is tough to figure out what is going on. Take me. I studied nuclear fusion for my doctorate. That's when the nuclei of two light atoms fuse together and give off a bunch of energy.

If you could coax lithium nuclei or boron nuclei to fuse with protons under the right conditions (it has to be very, very hot before they will do that in sufficient numbers—actually much hotter than the insides of the Sun), we would have a source of energy that would be next to ideal. It would use plentiful non-radioactive, relatively non-toxic materials as fuels. It has inert helium nuclei as end products, which would be collected directly on electrodes to make electricity. It would be like a nuclear fusion battery. No mess, and practically no water needed even. But it is tough to achieve the high temperatures needed for such nuclear fusion reactions. Even much simpler controlled fusion schemes have not been demonstrated to be feasible. But we do know how to make nuclear fusion bombs, triggered by nuclear fission bombs.

That's where the trouble really started—nuclear fission. The raw materials are radioactive and long-lived—like uranium-235 and plutonium-239. Inhaling them is not recommended as they increase cancer risk. Critical masses of these materials can be assembled to make bombs that flatten cities and kill vast numbers at a single stroke—also not recommended. These atoms must be fissioned to yield energy. Many of the fission products, elements like cesium-137 and strontium-90, in the middle of the periodic table, are also radioactive. Some, like cesium-135 and iodine-129, are very long-lived. This creates a nuclear waste problem whose safe long-term management has so far eluded science and technology.

This is not for lack of smarts. But it has proved too tough to design schemes assuring that (i) future miscreants would not mine the wastes for plutonium to make bombs and (ii) the containers would not deteriorate and contaminate water that people tens of thousands of years from now would use for drinking and irrigation.

Now many in the nuclear establishment think that they've got the problem licked, if the public would just trust them. But after having been told that nuclear power would be too cheap to meter, and that plutonium would provide a "magical energy" source if the public would support a "nuclear priesthood" to guard the waste (what Alvin Weinberg, the first director of Oak Ridge National Lab, said in 1972), and that the risks to retarded schoolchildren fed radioactive cereal in a human experiment were "insignificant when compared to overall cancer mortality in the United States," trust may just be the commodity that the nuclear establishment may find hardest to come by. (The latter statement was given in testimony to the U.S. Congress in 1994 by the then-president of the Health Physics Society, Dr. Kenneth Mossman. He was subsequently asked whether he would give the cereal to his own son. He said "No.")

Don't get me wrong. Nuclear energy from fission has some advantages, like low carbon dioxide emissions. But nuclear fission power plants (the only kind we know how to build) create plutonium, spread the know-how for nuclear fission and hence, to a large extent, for nuclear bombs, create long-lived waste, and are expensive. While different designs of power plants have different risk levels and accident mechanisms, accidents on the scale of Chernobyl are possible in all commercial nuclear power plant designs.

We know how to provide for the electricity needs of society in much better ways than either emitting vast amounts of greenhouse gases or making plutonium. And we can do it for about the same amount of money or less. So why incur the proliferation, waste, and accident risk headaches of nuclear fission?

So apart from my inevitable attachment to the nuclear material I got from my parents, I am neither pro-nuclear nor anti-nuclear. I make unsentimental calls on technology, keeping an eye on cost, environmental impact, reliability, and technoweenie things like that. I like p-lithium and p-boron nuclear reactions because they make technical and environmental sense. Society should invest more in that nuclear technology to try to make it happen. Nuclear fission power has too many proliferation and waste headaches and we can do without it. It's time to move on.

—Arjun, a.k.a. Dr. Egghead

It pays to increase your jargon power with Dr. Egghead

Greenhouse gas emissions:

a. Vapors that cause the windows of plant nurseries to fog up.

b. Foul odors emanating only from homes painted a deep shade of chartreuse.

c. Gases emitted into the atmosphere that trap infrared radiation and affect the earth's temperature and climate. The most important greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), several categories of halogenated organic chemicals (such as chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Coal gasification:

a. Misspelling of a German method of converting cabbage into noxious gases. Originally kohlgasification.

b. Same as cola gasification—the injection of carbon dioxide into sodas.

c. A process in which coal, steam, and oxygen are reacted at high temperature and pressure to produce a mixture of carbon monoxide, carbon dioxide, hydrogen, and methane, which is typically then used as an energy source or feed stock.

Carbon sequestration:

a. Code name used by coal miners in the 19^{th} century for kidnapping the mine owner until better working conditions were met.

b. The famous case of the imprisonment by Napoleon Bonaparte of his brother, CARlos BONaparte, nicknamed Carbon, accused of conspiring to dethrone him in a plot code named "Heat Trap."

c. Also called carbon capture and storage. The collection, concentration, transport, and long-term storage of carbon dioxide produced from fossil-fuel-burning power plants. The CO_2 is usually stored in geologic formations such as depleted oil and gas fields or deep saline aquifers.

Pyroprocessing:

a. Procedures law enforcement officials must follow to bring an accused arsonist to justice.

b. Culinary term for preparing a pie of roe (fish eggs).

c. The electrolytic separation of the contents from spent nuclear fuel into several streams, including uranium, a mix of plutonium and transuranic radionuclides, and fission products. Also called electrometallurgical processing. Pyroprocessing can be done in more compact facilities than traditional reprocessing, which therefore may aggravate proliferation risks.

Kyoto Protocol:

a. A saying used to teach children how to pronounce their o's.

b. Proper manners when visiting Kyoto, Japan, whereby the visitor must present a gift to the first environmentalist s/he encounters.

c. An agreement pursuant to the UN Framework Convention on Climate Change whereby highly industrialized countries agree to legally binding commitments to reduce emissions of six major greenhouse gases. Entered into force February 2005 and, as of April 2006, had 163 state parties. The largest emitter of greenhouse gases, the United States, signed the Protocol but did not ratify it and is not implementing it.

Pumped hydro storage:

a. A marina for housing a very macho speedboat.

b. Closet for the equipment used in the exercise class "Pumped Hydro" that combines water aerobics and weightlifting.

c. An energy-generating system in which water is pumped from a lower to higher elevation and into a reservoir, storing off-peak electrical energy as gravitational energy. When released, the water passes through hydraulic turbines, which drive electric generators.

Distributed electricity grid:

a. The network of wall outlets in one's home.

b. In a socialist economy, an energy system in which each person is allotted the same amount of electricity.

c. The electricity grid is the system of transmission lines and power generating stations (usually large and centralized) that transmits electricity from producer to consumer. In a *distributed* grid, a substantial proportion of the electricity would come from relatively dispersed or decentralized generators connected to the grid through local distribution systems.

Answers: c, c, c, c, c, c

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secondarily hydropower, France is not required under the Kyoto Protocol to reduce its CO_2 emissions below their 1990 level, unlike other western European countries.

Iconic status tends to breed mythology. Some believe that France has solved its nuclear waste problem.[2] Yet, the problem of nuclear waste festers in France, at or near the epicenter of the nuclear debate.[3]

Nuclear power advocates, having lost their slogan "too cheap to meter" to the reality of high cost, have now found a new sales pitch—that nuclear power will help solve the problem of CO_2 emissions from the electricity sector, and possibly from the entire energy sector via hydrogen production in specially designed reactors. Brice Smith's article in this issue addresses the risks associated with such use of nuclear power. This article addresses the icon, France. The central question we posed is: Could France decide to phase out nuclear power and achieve substantial reductions in CO_2 emissions simultaneously over the next several decades?

> Could France simultaneously phase out nuclear power and achieve substantial reductions in CO_2 emissions over the next several decades?

We will first examine the pattern of energy use in France and briefly discuss its evolution over the last few decades. This will set the context for the discussion of the scenarios that we constructed showing that France could indeed phase out nuclear power and achieve about 20 percent reduction in CO_2 emissions by mid-century with existing or near-existing technology (IEER ET scenario), and about 40 percent reduction with more advanced technology that is available at present but may not be economical as yet (IEER AT scenario).

France's energy system: its evolution and vulnerabilities

Oil showed its muscle in the naval battles of World War I, after which Senator Bérenger of France called it the "blood of victory"; it would also be the "blood of peace" he said. "More oil, ever more oil" was the rallying cry of the French. It, indeed, was the policy of all the major powers.[4]

France's lack of control of its main sources of oil during World War I (it did not have domestic petroleum sources or colonies that were oil-rich then) led to "the birth of an obsession: energy independence."[5] Its response was to acquire and control foreign sources of oil and create an oil company with the mandate to manage the German share of the Turkish Petroleum Company it acquired after WWI.[6] The oil company, the Compagnie Françaises des pétroles, although a private company, had a close relationship with the government.

After World War II, the French government nationalized the remaining sectors of the energy system. This move allowed for the development of domestic resources in the electricity sector, hydropower and coal, to respond to the growing electricity demand. Between them they generated about 90 percent of the electricity in 1960. However, soon after, cheap oil began to replace increasingly uncompetitive domestic coal and in 1973 the contribution of coal was only 16 percent of electricity generation, while the share of oil rose to 39 percent; hydropower contributed 27 percent. Hence, the first great transformation of the electricity sector in post-World War II France was from coal to oil; it took about three decades.

The vulnerability of this system to price and supply shocks was brought into stark relief by the 1973 oil crisis, which included large crude oil price increases and the Arab oil embargo against the United States. At that time, nuclear energy was a relatively minor part of the French electricity sector—8 percent. A decision was made, without broad debate, to speed up France's civilian nuclear energy program. Nuclear energy increased from 8 percent to nearly 80 percent by the end of the century—also less than three decades. Table 1 shows the pattern of energy supply in France in the year 2000.

But nuclear power alone could not guarantee energy independence. Fearing a shortage of uranium resources and sharp increase in prices, France dreamed of a plutonium economy based on breeder reactors fueled by plutonium extracted from spent uranium fuel discharged from its pressurized water reactor (PWR) plants.

The use of nuclear energy enabled France to eliminate oil from its electricity sector. Yet oil use in France's entire energy sector is still quite high. This is because transportation energy use is centrally oil-driven, with motor vehicles and aircraft leading the way. Petroleum use in the industrial sector is also significant. Natural

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TABLE 1: TOTAL ENERGY CONSUMPTION BY SOURCE IN FRANCE IN 2000
(in million metric tons of petroleum equivalent (Mtep) and percent)

	Coal	Oil	Natural Gas	Nuclear + hydro	Other	Total
Mtep	14.1	98.5	37.3	94.9	12.7	257.6
%	5.5	38.2	14.5	36.9	4.9	100

Source: Adapted from p.20 of *Bilan énergétique provisoire de la France en 2000*, on the Web at www.industrie.gouv.fr/energie/pdf/bilan2000.pdf.
Notes: One Mtep is equivalent to 42×10^{12} joules. Hydroelectric energy is converted into thermal equivalent: 1 MWh electrical = 0.222 tep thermal.

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gas is also widely used in the industrial sector and for heating in the residential and commercial sectors.

France claims that the move to nuclear was centrally responsible for enabling it to achieve a 50 percent level of energy independence. However, if the term "independence" is interpreted as domestic production of fuels only, then the official claim does not hold up. Because France imports all of its uranium supply, the inclusion of this fuel as contributing to "energy independence" is incorrect. It is no more reasonable to include electricity based on imported uranium as "domestic" than it is to include electricity generated form imported oil as "domestic."

Had France been able to base its nuclear power sector on plutonium fuel made in its own reactors, the claim would have much more merit. But France's plutonium dream turned into a financial nightmare because its demonstration commercial breeder reactor, the 1,200 megawatt Superphénix, turned out to be a lemon.

The Superphénix operated at an average capacity factor of about 7 percent over its 14-year life before it was permanently shut down in 1998. After spending about 20 billion dollars to try to commercialize plutonium, France was reduced to subsidizing the uneconomical use of plutonium fuel (MOX fuel) in twenty of its 58 light water reactors to the tune of about $1 billion per year.[7] Since only 30 percent of the cores of these reactors are fueled with MOX, the contribution of domestically-produced plutonium to the French electricity sector is less than 10 percent.

Overall, France produces only about 15 percent of its energy requirements domestically—an historically low figure, largely deriving from its continued reliance on nuclear and on fossil fuels in large sectors of its economy, as noted above.

France has achieved increased security in its energy system since 1973, but at the cost of new vulnerabilities. Diversifying its electricity sector into nuclear from heavy reliance on oil has not materially reduced imports of fuel, but it has increased France's energy security by increasing diversity of energy supply. France has also reduced its emissions of carbon dioxide in the electricity sector by relying mainly on nuclear and hydropower. This is an important factor that must be taken into account in any scenario that aims to reduce greenhouse gas emissions in France.

Despite these significant advantages, France continues to have significant energy system vulnerabilities and has acquired new ones:

- High oil imports, and the almost total dependence of the transportation sector on them, continue to be a crucial vulnerability despite the large role of nuclear power in the economy.
- France's CO_2 emissions continue to rise mainly due to increasing use of petroleum.
- Its highly centralized electricity system is vulnerable to terrorist attack.
- Nuclear waste management has become a major technological, financial, environmental, and social problem.
- A single accident on the scale of Chernobyl could devastate the economy and society of France.
- Decommissioning its vast nuclear system, including its breeder reactors and its reprocessing plants, will be very expensive.
- France is contributing to proliferation problems, notably in the case of Japan, by exporting commercial plutonium. Some Japanese leaders advocate that Japan should consider becoming a nuclear weapon state; one, Ichiro Ozawa, has explicitly noted that Japan could use nuclear materials from the commercial sector to make thousands of nuclear weapons.

These realities have led many in France to express concern about its reliance on nuclear energy. There will be no easy exit. But it is possible.

> The two great transformations of France's electricity sector—from coal and hydro to oil and hydro, and from there to nuclear—each took less than three decades.

IEER energy scenarios for France

Reducing CO_2 emissions and phasing out nuclear power poses special challenges in France. First, prematurely retiring a significant number of nuclear power plants would require additional investments that could otherwise be used to reduce CO_2 emissions in other sectors. Second, France's electricity grid is highly concentrated and oriented to the locations of its nuclear power plants. Third, while France has significant wind energy resources, they are not sufficient to anchor the electricity system in the way that nuclear power does today, even apart from the problem of the intermittency of wind. (In this respect, France is unlike the United States, where wind energy resources are very abundant.) For these reasons, the approach that we used to address the issue of simultaneous nuclear power phase-out and CO_2 emissions reductions is to assume that nuclear power plants would be retired at the end of their licensed lifetimes.

IEER's basic approach to achieving significant carbon dioxide emissions reductions and a nuclear power phase-out consists of the following elements:

- A much more efficient energy sector in all the major areas of energy use—residential, commercial,

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industrial, and transportation, and;

- A transition from an energy supply system based mainly on oil and nuclear to a mix of natural gas, oil, and renewable energies.

To demonstrate the economic and technical feasibility of making the major transition to a lower CO_2 and non-nuclear energy system, we have taken the rather conservative approach of considering technologies that are already commercial, that can be made commercial with modest effort, or those that can be made commercial with a significant amount of investment that face no essential scientific hurdles. We use the first two to define the IEER Existing Technologies scenario (IEER ET scenario) and all three to define the IEER Advanced Technologies scenario (IEER AT scenario). The scenarios estimate the energy sector in the year 2040 compared to that in 2000.

IEER's energy scenarios use the same demographic and economic parameters as the scenario S1 (referred to hereafter as the "business-as-usual" scenario) of the Commissariat Général du Plan (France's national planning commission) in its 1998 report, *Energie 2010-2020*, which presents projections to the year 2020 for France's entire energy sector.[8] In scenario S1, the energy requirements are high and accompanied by high carbon dioxide emissions. We show that with the same level of energy services as in the S1 scenario, France can achieve a substantial reduction of its CO_2 emissions.

Components of the transformation of the various energy demand sectors and their fuel supply can be summarized as follows:

- Transition to high efficiency space-conditioning systems for the residential and commercial sectors (such as earth source heat pumps and cogeneration), with an increase in efficiency.

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FIGURE 1: ENERGY CONSUMPTION PROJECTION FOR 2040: BUSINESS-AS-USUAL

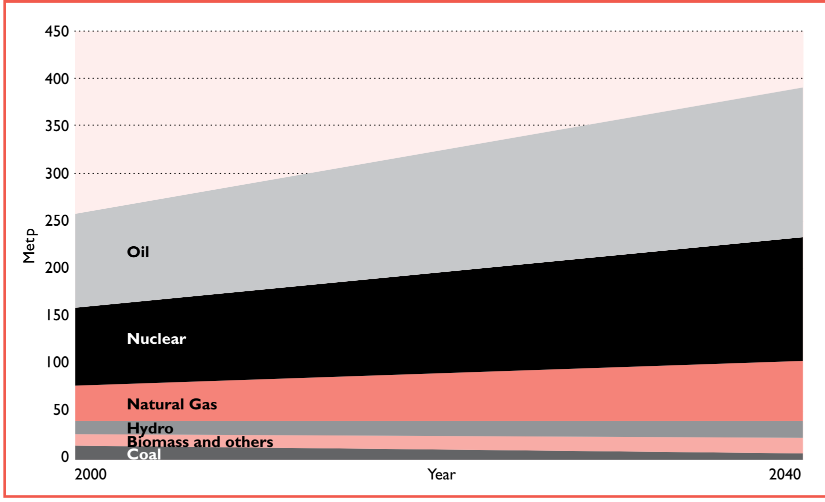


FIGURE 2: ENERGY CONSUMPTION PROJECTION FOR 2040: IEER ET SCENARIO

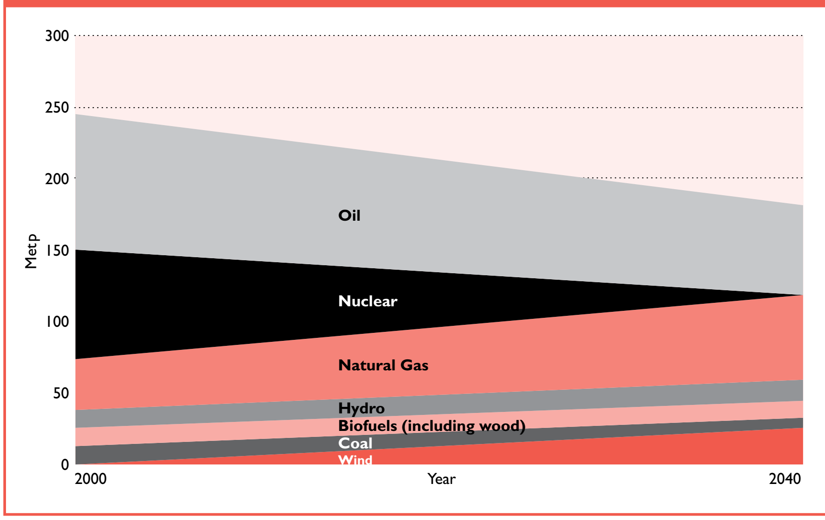
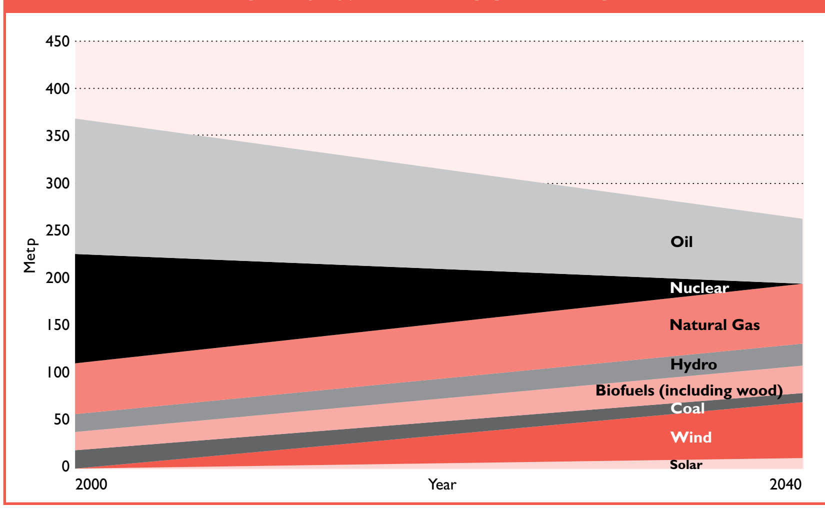


FIGURE 3: ENERGY CONSUMPTION PROJECTION FOR 2040: IEER AT SCENARIO



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- For the electricity sector, a transition from nuclear power and hydro to natural gas and renewables (wind, hydro, and biomass in the ET scenario and solar in the AT scenario). Wind energy plays a large role in both IEER scenarios. Solar energy plays a large role only in the AT scenario.
- For the transport sector, a large reduction in the use of oil and drastic increases in efficiency, with implementation of mileage standards of 2.4 liters per 100 kilometers (about 100 miles per gallon) for new passenger vehicles over about two decades with gradual improvements after that (ET scenario). The use of plug-in hybrid vehicles is included in the AT scenario.
- Combining natural gas combined-cycle power plants, pumped hydro storage, and natural gas turbine standby with renewable energy sources to produce a reliable electricity system.

The results that would arise from the implementation of the ET and AT scenarios are presented in Figures 1 through 4. They show that in 2040 energy consumption under the business-as-usual scenario would be about two times higher than that for the IEER ET scenario for the same level of energy services. Carbon dioxide emissions would be 2.2 times higher.

Electricity sector details

Under the technological assumptions used in the IEER ET scenario for the various sectors, we estimate that almost 450 TWh (terawatt-hours) of electricity would be required to provide for the same level of energy services as in the business-as-usual scenario.[9] Table 2 shows the fuels and the distribution of electricity generation among them used in 1995 and those needed to meet the level of energy services provided by electricity in the year 2040 as projected under IEER's ET and AT scenarios. (As noted, the level of consumption of energy services, such as transportation, housing, commercial sector space, etc., remain the same as under the business-as-usual scenario, but the IEER scenarios use less fuel and more efficient end-use technology.)

The intermittency of wind is compensated by making provision for energy use in pumped hydropower, whereby water is pumped back into reservoirs at non-peak times when there is a surplus of wind energy. There is also provision for standby natural gas to generate electricity equal to about 5 percent of the wind electricity

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FIGURE 4: COMPARISON OF CARBON EMISSION PROJECTIONS IN ALL SECTORS

Business-As-Usual versus IEER ET and AT Scenarios

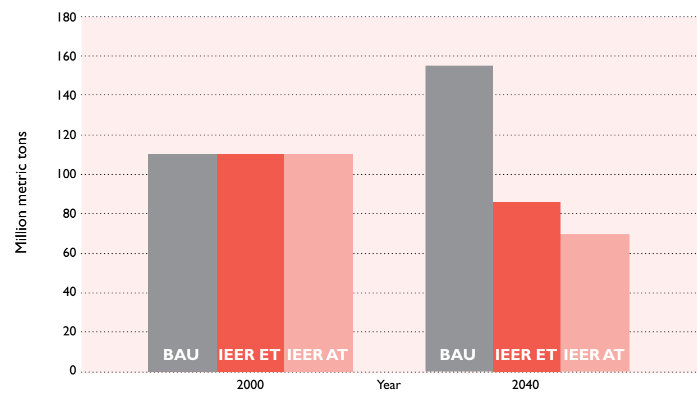

TABLE 2: IEER ET AND AT SCENARIOS FOR FRANCE'S ELECTRICITY SECTOR STRUCTURE

(in terawatt-hours per year and percent)

	1995		2040 ET scenario		2040 AT scenario	
Source	TWh	%	TWh	%	TWh	%
Wind	0	0	126	28	181	42
Coal	22	5	0	0	0	0
Biomass and miscellaneous	0	0	40	9	20	5
Hydro	76	16	74	17	74	17
Gas	13	3	204	46	117	27
Nuclear	359	76	0	0	0	0
Oil	2	0	0	0	0	0
Solar	0	0	(See note 1)		35	8
Total	472	100	444	100	427	100 (see note 2)

1 Energy sources such as landfill gas and solar are included in the "Biomass and miscellaneous" row for the ET scenario.
2 Total in the last column does not add to 100 due to rounding.

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generation. Both these measures would make up for shortfalls in periods of low wind speed. The overall cost of such measures is not expected to result in wind energy costs higher than nuclear electricity (see accompanying article by Bruce Smith).

Oil and gas

France's oil consumption in the year 2000 was about two million barrels per day and is expected to go up to slightly over three million barrels per day in 2040, according to business-as-usual projections.[10] Currently about half the oil is consumed in the transport sector, and the rest is used mainly as a source of heat and hot water in the residential, commercial, and industrial sectors (and a comparatively small amount in agriculture), and also as feedstock in the industrial sector. Under the IEER scenarios, the consumption of oil will be totally eliminated in the residential and commercial sectors and drastically reduced in the industrial sector where it will be only used as a feedstock.

An efficiency increase to 100 miles per gallon in the next two decades and continued increases after that would cut transport sector emissions of carbon by about 65 percent compared to the business-as-usual scenario, to 33 million tons of carbon. This is about 30 percent less than transport sector CO_2 emissions in the year 2000.

The use of natural gas in the IEER scenarios is estimated to be about the same as in the business-as-usual approach. Coal would be eliminated except in steel production.

Overall, due to the use of wind, hydro (as the same level as at present), and improvements in efficiency that result in lower energy use for a much larger supply of energy services (like lighting, refrigeration, and transportation), the proportion of domestically produced energy in France would go up from 15 percent in the year 2000 to about 25 percent (ET scenario) or more (AT scenario). The diversity of energy supply would be somewhat greater. The dependence on imported oil and gas would continue, but the vulnerability to disruption of oil supply would be considerably reduced due to reduced oil imports. Strategic petroleum reserves would last longer under the IEER scenarios compared to the business-as-usual approach. Finally, nuclear-related vulnerabilities would be largely eliminated, though the liabilities of waste management and decommissioning will likely remain well beyond the year 2040. In particular, the problem of decommissioning reprocessing and related facilities will impose considerable costs.

The net costs of reducing CO_2 emissions can be kept modest with the right policy choices and monitoring of the effects of those choices.

Carbon dioxide emissions

Energy use in the business-as-usual scenario would be 390 million metric tons of petroleum equivalent (Mtep) in 2040. Energy use in the IEER ET scenario is cut by more than half of the business-as-usual reference case, to 191 Mtep. The reduction in CO_2 emissions in the IEER ET scenario compared to business-as-usual is about 44 percent. The reductions in CO_2 emissions are relatively less than energy use reductions because much of the nuclear electricity generation has been replaced by natural gas generation. However, the latter is highly efficient (much more so than nuclear) and also the CO_2 emissions per Mtep from natural gas use are only half of those of coal.

When compared to CO_2 emissions in the year 2000, the reduction in the IEER ET scenario is just over 20 percent. This is significant, especially given that nuclear power is also phased out. However, it is rather modest compared to the need to reduce CO_2 emissions by ~80 percent in order to achieve goals related to minimizing the risk of severe climate change.

In the IEER AT scenario, the energy use at 186 Mtep is comparable to the energy use in the ET scenario. This is because the focus of the CO_2 reduction measures was largely on the supply side. Under the IEER AT scenario, the CO_2 emissions are 40 percent lower than in the year 2000, due to greater implementation of energy efficiency and use of renewable energy than in the IEER ET scenario.

Energy policy considerations

While choosing technologies to produce large reductions in CO_2 emissions with a nuclear power phase-out poses significant difficulties in the case of France, the real challenge is in the policy arena. The net costs of reducing CO_2 emissions can be kept modest with the right policy choices and monitoring of the effects of those choices. The most important determinant is getting the right public policy choices. Mandatory reductions of CO_2 emissions beyond that required by the Kyoto Protocol are essential. France will also need to make the decision to phase out nuclear energy. The least difficult component of that decision should be the elimination of reprocessing, which is a considerable net burden on the French economy.

Other than these necessary goals, our principal recommendations are as follows.

1. A mileage standard of 100 miles per gallon (2.4 liters per 100 kilometers) for new passenger vehicles should be set over the next two decades with gradual improvements after that.

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2. A transition to a distributed electricity grid should be achieved over the next four decades.

3. A national and regional procurement program of 5 billion euros per year for at least ten years should be enacted to purchase renewable energy, earth source heat pumps, efficient automobiles, and other leading edge technologies at efficiencies that are higher than those available on the open market in order to promote the commercialization of progressively more efficient technologies and renewable energy. All subsidies other than those implicit in this procurement program should be eliminated.

4. France should create a task force to address the fiscal implications of greatly reducing the use of gasoline, which is heavily taxed, over the long-term. One revenue option would be to tax new cars and other motor vehicles that have efficiency below certain levels, which would increase with the years.

5. France should enact rules for existing and new residential and communal buildings that will result in drastically increased building envelope efficiency and through increased use of technologies such as earth source heat pumps and cogeneration.

1 This article is based on the IEER report, *Low Carbon Diet without Nukes in France,* which can be downloaded from IEER's website www.ieer.org. Details of the references and scenarios can be found in the full report.

2 For instance, see the statement by U.S. Vice-President Dick Cheney quoted in IEER's press release concerning France and nuclear waste, online at www.ieer.org/comments/waste/chen-prl.html.

3 For an investigation into France's repository program see Arjun Makhijani and Annie Makhijani, "Disposal of Long-Lived Highly Radioactive Wastes in France: An IEER Evaluation," SDA Vol. 13. No. 4, January 2006. On the Web at www.ieer.org/sdafiles/13-4.pdf.

4 Senator Bérenger as quoted in Daniel Yergin. *The Prize: The Epic Quest for Oil, Money, and Power.* New York: Simon & Schuster, 1991. Page 183.

5 François-Xavier Ortoli. "Le pétrole: enjeux et défis pour la France." *Revue des Sciences Morales et Politques* 151e année, No 3 (1996). page 295. As quoted by Pierre Noël in "Indépendance énergétique versus marché mondial" (Genoble: Institut d'Etudes Politiques et IEPE, 1999). On the Web at www.upmf-grenoble.fr/iepe/textes/Noel9910.PDF. Translation by Annie Makhijiani.

6 François Roche. *TotalFinaElf : une major française.* Paris: Le Cherche midi, 2003. Pages 24 and 25.

7 Arjun Makhijani. *Plutonium end game: managing global stocks of separated weapons-usable commercial and surplus nuclear weapons plutonium.* Takoma Park, MD: Institute for Energy and Environmental Research, January 22, 2001. On the Web at www.ieer.org/reports/pu/

8 François Moisan. *Énergie 2010–2020: Rapport de l'Atelier, Trois scénarios énergétiques pour la France.* Paris: Commissariat Général du Plan, Septembre 1998. Président, François Moisan. Rapporteur, Olivier Godard. Summary on the Web at www.industrie.gouv.fr/energie/prospect/pdf/trois-scenarios.pdf.

9 One terawatt-hour equals one trillion (10^{12}) watt-hours, which is the same as a billion kilowatt-hours (10^{9} kWh). One watt-hour is one watt of power used for one hour. For example, a 40-watt light bulb uses 40 watt-hours of electricity every hour it is turned on.

10 IEER calculated these numbers from data found in Moisan 1998.

HOT IEER Materials on Energy Issues

Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change
By Brice Smith (RDR Books/IEER Press, 2006, 519 pages, paperback)
www.ieer.org/reports/insurmountablerisks/

Low-Carbon Diet without Nukes in France: An Energy Technology and Policy Case Study on Simultaneous Reduction of Climate Change and Proliferation Risks
IEER report by Annie Makhijani and Arjun Makhijani, May 4, 2006
www.ieer.org/reports/energy/france/

An Update on Nuclear Power — Is It Safe?
Talk by Arjun Makhijani at Policy Maker Education: Course for Congressional Staff sponsored by Harvard Medical School, April 19, 2006 (Streaming video: requires RealPlayer)
http://estream.med.harvard.edu:8080/ramgen/Content/CustomVideo/HHGE/C_04272006080523.rm

Nuclear Energy
Interview with Arjun Makhijani on NPR's *Science Friday,* February 24, 2006
www.sciencefriday.com/pages/2006/Feb/hour1_022406.html

Our Electric Future: A Non-Nuclear Low Carb Diet?
Interview with Arjun Makhijani in the Fall 2005 *New Hampshire Sierran*
www.ieer.org/latest/ourelectricfuture.html

Energy Bill / Nuclear Energy
Interview with Arjun Makhijani on *NPR's Science Friday,* June 17, 2005
www.sciencefriday.com/pages/2005/Jun/hour1_061705.html

Costs and Risks of Depleted Uranium from a Proposed Enrichment Facility
Article by Arjun Makhijani and Brice Smith in *Science for Democratic Action,* June 2005
www.ieer.org/sdafiles/13-2.pdf

Uranium Enrichment: Facts to Fuel an Informed Debate on Nuclear Proliferation and Nuclear Power
Article by Brice Smith in *Science for Democratic Action,* March 2005
www.ieer.org/sdafiles/13-1.pdf

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