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Nuclear Power Costs: *High and Higher*

BY ARJUN MAKHIJANI, Ph.D.[1]

After the spectacular crash of the 1950s propaganda of nuclear power that would be "too cheap to meter," evidenced in dozens of cancelled nuclear power plants because they were too costly to build or complete, there is a new push for nuclear power in the United States. Some advocates of a nuclear power "renaissance" are basing their appeals on the notion that nuclear power will be an inexpensive way to get new baseload capacity and to combat global warming. Others believe that it may become economical if there is a high enough price on carbon dioxide emissions.

Cost estimates of nuclear power

The principal cost associated with commercial nuclear power is the capital cost of the plant. Operating costs consist of fuel, which is generally low enriched uranium; other operating and maintenance costs constitute a relatively small fraction of the total cost of nuclear power. The costs of spent fuel management and disposal as well as decommissioning costs would be in addition to these two items.

Capital costs of nuclear power consist mainly of two components:

- The "overnight cost" of the power plant – this is the cost that would be incurred if the plant could be built at once.
- Additional costs incurred during construction, notably interest costs.

The overnight cost of nuclear power is a matter of some debate. A 2003 MIT report, which advocates building nuclear power plants, estimated it at $2,000 per kilowatt (kW), while a 2004 University of Chicago study estimated it at $1,500 per kW.[1] Current U.S. estimates and actual experience in Western Europe with the European Pressurized Water Reactor are much higher.

For instance, the CEO of Duke Energy, which wants to build nuclear power plants, gave his estimate of the capital cost of $2,500 to $2,600 per kW.[2] Using $2,500 per kW as the starting point, the overnight capital cost contribution to electricity cost alone is over 4 cents per kilowatt-hour (kWh). Interest during construction would add 1 to 2 cents per kWh (depending on borrowing rates, risk premium, and construction time). Fuel costs and other operating and maintenance costs are 1.5 to 2 cents.[3] Adding 0.1 cent per kWh for spent fuel disposal (the current federal charge) and a small charge for decommissioning[4] gives a total cost of about 7 cents to over 8 cents per kWh.

These are costs based on industry figures and the assumptions of those who favor nuclear power. A more realistic consideration was made by a joint fact-finding committee, which included nuclear industry personnel as well as those more skeptical of a renewed role for nuclear power. It was put together by the Keystone Center. Its cost investigation concluded that completed nuclear power plant capital costs, including interest during construction, would be in the range of $3,600 to $4,000 per kilowatt. The resultant cost estimates are shown in Table 1, on the following page, reproduced from Table 6 of the Keystone Center's report.

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Solar Grove, San Diego, California. The parking lot of Kyocera's North American headquarters is a 25-panel, 235-kilowatt solar electric generating system that also provides shade for 186 vehicles. (Copyright 2007 Kyocera Solar, Inc. All rights reserved.)

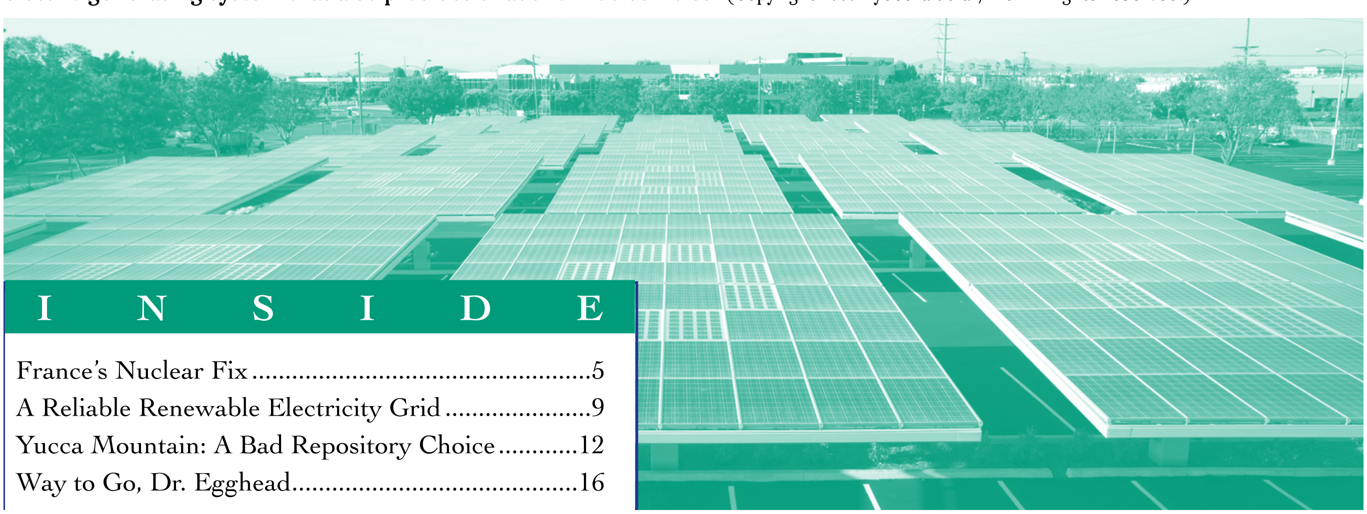

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Table 1: Estimated nuclear electricity costs from new power plants in the United States

Cost Category	Low Case	High Case
Capital Costs	4.6	6.2
Fuel	1.3	1.7
Fixed O&M	1.9	2.7
Variable O&M	0.5	0.5
Total (Levelized Cents/kWH)	**8.3**	**11.1**

Source: Keystone Center

Real world experience is proving to be even more problematic. The only nuclear power plant being constructed in the West that is well along in its construction is a European Pressurized Water Reactor (EPR) being built in Finland by AREVA, the French reactor vendor and reprocessing company. The cost of the reactor, which is rated at 1,600 megawatts, was originally estimated at 3 billion euros, but it has now escalated to 4.5 billion euros. At the present rate of exchange, this amounts to about $4,000 per kW, which is at the high end of the capital cost estimate made by the Keystone Center report. Moreover, the reactor is not yet complete. So far, there has been a two year delay.[5]

> Wall Street casts a skeptical eye on nuclear power plants and no company is ready to order one without federal loan guarantees.

Notably, AREVA made a turnkey contract with Finland, agreeing to absorb all costs more than 3.2 billion euros.[6] Since the company is about 85 percent owned by the French government, French taxpayers will pick up most of the cost overrun. Evidently, the hidden hand of the nuclear power industry is to be found in the pocketbooks of taxpayers' or ratepayers, or both.

Wall Street and nukes

No new nuclear power plants have been ordered in the United States since 1978. The last one that was actually completed and put into operation was ordered in October 1973.

The risks of nuclear power are such that Wall Street casts a skeptical eye on nuclear power plants and no company is ready to order one without federal loan guarantees. That is why despite all the talk of a "nuclear renaissance," no company in the United States has as yet ordered a nuclear power plant, though some have applied for various kinds of licenses that will be necessary to build one. The nuclear industry is waiting with a large hat in hand for 100 percent loan guarantees from the federal government, which would lower interest costs.

The Wall Street firm Moody's estimated in October 2007 that the "all-in" capital nuclear costs of new nuclear plants (including interest during construction and upgrades to existing sites with nuclear power plants needed for construction) were being underestimated and that they would likely be in the range of $5,000 to $6,000 per kW. Using the latter figure would increase the Keystone Center report's upper end estimate of nuclear

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electricity from new plants to about 14 cents per kWh (since the capital cost would increase from 6.2 cents per kWh to about nine cents per kWh).

Views from the industry

Many in the industry, such as the Duke Energy CEO, understand that nuclear power is risky, which is why they are pressing for government loan guarantees. However, some would-be nuclear entrepreneurs are still promoting a retro-1950s fantasy of cheap nuclear power.

For instance, the 2007 Integrated Resource Plan of the western U.S. electricity producer PacifiCorp estimates that a new nuclear power plant can be built for $2,635 per kW, including interest during construction. Using a low effective rate for interest and return on equity, the annual capital charges are estimated at only $210.97 per kW.[7] At an 85 percent capacity factor, this means that the capital cost of nuclear power would amount to only 2.8 cents per kWh in 2006 dollars. This is lower than the MIT study, which was done in 2003 — and costs have escalated for nuclear as well as coal-fired and wind power plants since that time.

PacifiCorp further estimates operating and maintenance costs of about 2.3 cents per kWh, for a total cost of electricity of about 5.1 cents per kWh. Given the trends in costs, this is far lower than any realistic estimate of nuclear electricity, such as that in the Keystone Center study or the actual costs being incurred in the Finnish EPR project. It would be interesting to know if PacifiCorp would stand behind its estimate and provide a turnkey project to, for instance, the State of Utah along the same lines that AREVA provided to Finland — that is, a fixed total installed cost, including all construction and interest costs.[8]

As a more extreme example, Alternate Energy Holdings, Inc., proposes to build the European Pressurized Water Reactor in Owyhee County in southwestern Idaho. In a radio interview on July 30, 2007,[9] the following interchange took place between the host and the company's CEO, Don Gillispie:

> Interviewer: And it's a 3.5 billion dollar plant.
> Mr. Gillispie: Yeah. They're not cheap. New plants produce electricity power very cheaply but they have high capital cost. Normally the capital cost, as you may know, in any investment is not borne by the, it's really borne by the investors pretty much and the lenders, but essentially we can produce electricity between 1 and 2 cents a kilowatt-hour. There is nothing in the United States that can do that. The only thing that comes close to that is hydro. Of course, we're dying on hydro. Hydro's down to six percent of our power source in the U.S.

While part of Mr. Gillispie's statement is realistic — that expanding hydropower significantly is not a viable option — the rest of the exchange is misleading. First, fuel and non-fuel operating costs are very unlikely to be as low as one cent per kWh. The higher estimate of 2 cents would be more typical of current costs, into which the recent run-up in uranium prices has not been factored. Given high uranium prices and shortages of skilled labor, the operating and maintenance costs could well be higher. The Keystone Center report estimated them to be in the range of 3.7 to 4.9 cents per kWh. Even PacifiCorp estimated them at about 2.3 cents per kWh.

Second, while investors and lenders normally provide the capital, they do not do this as a public service or charity. They do it to get a return on investment. Given the risk of nuclear projects, investors would normally demand a premium for investing in them. These costs are included in the electricity rates and must be paid by consumers – that is, the people and businesses in Idaho who would purchase the power and those outside the state who may choose to buy it. These costs, including interest during construction, would be on the order of 4 to 6 cents per kWh, and possibly more.

Alternatives to nuclear

Besides all this, there is the real risk that nuclear power plants will be economically obsolete before they are built. Wind energy is already more economical than nuclear energy. Expansion of wind capacity is taking place rather rapidly, especially in some parts of the United States.

A review of solar photovoltaic (PV) costs in my book, *Carbon-Free and Nuclear-Free,* indicates that installed solar PV costs are likely to be $2,000 per peak kilowatt or less within the next decade.[10] The U.S. Department of Energy (DOE) expects solar energy to be competitive in a few years. It has stated that solar energy is "on track to reduce the cost of electricity produced by PV from current levels of $0.18-$0.23 per kWh to $0.05-$0.10 per kWh by 2015 — a price that is competitive in markets nationwide."[11]

Given this prognosis, solar electricity costs may well be about equal to or less than the costs of nuclear electricity by 2015, which is the earliest possible date at which a new nuclear power plant could come on line in the United States. Further, intermediate-scale solar energy, such as that installed on large commercial rooftops and in large parking lots (see photo on page 1), will not have transmission or distribution costs added to it, unlike nuclear electricity. If such installations supply entire neighborhoods, some distribution costs will be incurred, since investments to upgrade distribution systems will likely be needed. Typically, that cost might be 1 to 2 cents per kWh.

If the delivered cost of solar electricity to the commercial sector is in the 5 to 10 cents per kWh range and if that to the residential sector from intermediate station installations is in the 7 to 12 cents range, new nuclear power plants will become economically obsolete rather soon, possibly before the first example of the "nuclear renaissance" comes on line.

Nuclear electricity is at least as risky today as it was in the 1970s when a wave of plants was ordered, resulting in dozens of cancelled plants and tens of billions of dollars in wasted money. Will consumers and taxpayers have to bail out the nuclear industry again, incurring tens of billions of dollars in additional costs? They already have once in the

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form of "stranded costs" in the 1990s when nuclear utilities were deregulated.

This time the stakes are much higher than just money. We have precious little time to waste on pursuing false economic trails, particularly ones that create more nuclear waste and proliferation headaches than we already have. Those who say that nuclear power should "remain on the table" as an option should have the burden of proof, since IEER has already shown that a reliable electricity system can be built without it and without fossil fuels (see accompanying article on page 9).[12]

Endnotes

1. Massachusetts Institute of Technology, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge: MIT, 2003), on the Web at http://web.mit.edu/nuclearpower; University of Chicago, *The Economic Future of Nuclear Power* (Chicago: The University, August 2004), on the Web at http://www.anl.gov/Special_Reports/NuclEconAug04.pdf; and, Brice Smith, *Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change* (Takoma Park, MD: IEER Press; Muskegon, MI: RDR Books, 2006).
2. North Carolina Utilities Commission, *In the Matter of: Application for Approval for an Electric Generation Certificate to Construct Two 800 MW State of the Art Coal Units for Cliffside Project in Cleveland/Rutherford Counties.* E-7, Sub 790-Vol. 6, January 19, 2007.
3. The Nuclear Energy Institute gives fuel costs in 2006 as 0.46 cents per kWh and other operating and maintenance costs as 1.26 cents per kWh, for a total operating cost in 2006 of 1.72 cents per kWh. On the Web at www.nei.org/resourcesandstats/nuclear_statistics/costs.
4. The Nuclear Regulatory Commission estimates that shutting down and decommissioning a reactor "may cost $300 million or more…." See www.nrc.gov/reading-rm/basic-ref/students/decommissioning.html. The Keystone report assumed a decommissioning cost of $500 million. Based on this the cost would be less than 0.1 cent per kWh. See Keystone Center, *Nuclear Power Joint Fact-Finding* (Keystone, CO: Keystone Center, June 2007), on the Web at www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf.
5. Myriam Chauvot, "Les nouveaux retards de l'EPR finlandais vont peser sur les comptes d'Areva," 13/08/07, on the Web at http://www.lesechos.fr/info/energie/4610065.htm.
6. Dominique Voynet, Coût du nucléaire français à l exportation pour le contribuable," 21 juin 2006, on the Web at http://dominiquevoynet.net/v2/index.php/2006/06/21/18-cout-du-nucleaire-francais-a-lexportation-pour-le-contribuable.
7. PacifiCorp used a payment factor of only 8.01 percent to estimate annual cost for an investment of $2,635. Interestingly, the company assumed a higher payment factor for wind power of 9.48 percent. (PacifiCorp, *2007 Integrated Resource Plan* (PacificCorp: Portland, OR, 2007), p. 95, on the Web at http://psc.state.wy.us/htdocs/dwnload/irp/2007PacifiCorpIRP.pdf).
8. Peter Bradford, former Nuclear Regulatory Commission member, suggested this as a strategy to officials in Utah during a visit there on November 2, 2007. PacifiCorp's IRP states that it is investigating nuclear power as a "viable option" for the future.
9. On the Web at www.alternateenergyholdings.com/news.html, viewed November 26, 2007.
10. Arjun Makhijani, *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy* (Takoma Park, MD: IEER Press; Muskegon, MI: RDR Books, 2007), pp. 37-40, on the Web at www.ieer.org/carbonfree/
11. United States Department of Energy, *DOE Selects 13 Solar Energy Projects for Up to $168 Million in Funding: First Funding Awards for Solar America Initiative to Make Solar Technology Cost-Competitive by 2015* (Washington, DC: DOE, Office of Public Affairs, March 8, 2007), on the Web at www.energy.gov/news/4855.htm.
12. Makhijani 2007, op cit.

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France's Nuclear Fix?

BY ARJUN MAKHIJANI, Ph.D.[1]

The nuclear establishment regularly points to France as the model nuclear energy state. Almost eighty percent of its electricity comes from nuclear power plants. It reprocesses its spent nuclear fuel to recover the plutonium, which it makes into mixed oxide fuel – a mixture of plutonium dioxide and depleted uranium dioxide called MOX fuel. This supplies 30 percent of the fuel for 20 of its 58 reactors.

This "recycling" is held up as the solution to nuclear waste problems — with the implication that France has solved them. All this is supposed to help solve the problem of reducing carbon dioxide emissions (and there is near general agreement that this is a global imperative of considerable urgency). Finally, the French public is said to be more sensible in that they support clean nuclear energy as distinct from the skepticism of the U.S. public.

Let us disentangle the fairy tales from the facts. First the facts from the side of the ledger that the nuclear establishment loves:

1. France does get nearly 80 percent of its electricity from nuclear power.
2. It does reprocess most of its uranium spent fuel at the largest commercial reprocessing facility in the world, located on the Normandy Peninsula at La Hague. France has two reprocessing units there, one for reprocessing domestic spent fuel and the other for foreign spent fuel. The site also stores highly radioactive liquid waste arising from reprocessing and highly radioactive glass logs that result from mixing the high-level liquid waste with molten glass. The volume of these radioactive glass logs is about a third of the volume of the spent fuel that is reprocessed.
3. France imports all of its uranium requirements.
4. MOX fuel generates less than ten percent of France's nuclear electricity.

Now for some of the inconvenient realities.

Pollution from reprocessing

Like every other country that has nuclear power plants, France has a large and complex nuclear waste problem that it is nowhere close to solving. Reprocessing and vitrification do reduce the volume of high-level radioactive waste, but they create other problematic waste streams.

For instance, the La Hague plant uses a pipeline to discharge hundreds of millions of liters of liquid radioactive waste into the English Channel each year, polluting the oceans all the way to the Arctic. This egregious pollution continues on the basis of a disingenuous renaming of liquid waste as "discharges." If the same waste were put into 55-gallon drums and dumped overboard from a ship, it would be illegal under the 1970 London Dumping Convention. But somehow the "discharges" are permitted. Twelve of the fifteen governmental parties to the Oslo-Paris agreement have asked France and Britain, which has two reprocessing plants in Northwestern England, to stop these discharges, to no avail. It is a weak treaty – the abstaining parties, Britain and France, are not required to comply.

Further, reprocessing creates new streams of solid waste. For instance, there are significant volumes of waste contaminated with plutonium, called long-lived intermediate-level waste in France, much of which is like transuranic waste in the United States. This is designated for disposal in a deep geologic repository, along with the highly radioactive vitrified waste. French waste data do not allow easy comparison of reprocessing and non-reprocessing waste volumes for repository waste. But it should be noted that the volume of French long-lived intermediate waste to be disposed of in a repository is more than ten times greater than the volume of high-level waste.[2]

Then there is the contaminated uranium that is recovered as part of the reprocessing system. Table 1 shows the approximate composition of fresh and spent fuel from a pressurized water reactor (the type used in France and also the most common one in the United States).

Table 1: Approximate composition of pressurized water reactor fuel (rounded)

Material	Fresh Fuel (weight percent)	Spent Fuel (weight percent)	Comments
Uranium-235	4	1	Each kilogram of enriched fuel creates about seven kilograms of depleted uranium in the course of enrichment
Uranium-238	96	94	
Plutonium (plus smaller amounts of other transuranic radionuclides)	0	1	Mixture of various isotopes from Pu-238 to Pu-242. Can be used to make nuclear weapons. Predetonation is more likely for bombs made with reactor-grade plutonium than with weapon-grade plutonium.
Fission products	0	4	Fission products contain the vast majority of the radioactivity in the spent fuel.

Note: Trace quantities of U-234 and activation products are not shown. Reproduced from Arjun Makhijani, Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy *(Takoma Park, MD: IEER Press; Muskegon, MI: RDR Books), 2007. On the web at www.ieer.org/carbonfree/.*

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Only about one percent of mass of spent fuel is plutonium. This is the part that is "recycled." This recycled part creates MOX spent fuel which has a degraded isotopic composition of plutonium that is more complex to reprocess and more difficult to use in light water reactors. Eventually MOX spent fuel will likely be disposed of in a deep geological repository along with the vitrified waste and transuranic waste.

Reprocessing and depleted uranium waste

Ninety-five percent of the mass of spent fuel is uranium, almost all of it uranium-238, which is not a fissile material. This uranium is contaminated with traces of fission products, plutonium, and other radioactive materials. In theory it can be re-enriched and used as a fuel, but since it is contaminated, it makes the problem of processing and enrichment of uranium more complex and costly.

For starters, the equipment for uranium processing and enrichment gets contaminated with these materials, which are much more radioactive per unit mass than natural or low-enriched uranium. France conveniently sends this contaminated uranium to Russia,[3] which apparently does not mind contaminating its enrichment plants. It should be noted that the U.S. compensation program for nuclear weapons workers exposed to radiation was triggered in large measure by the revelations that the Paducah enrichment plant in Kentucky had been contaminated with plutonium[4] and other transuranic radionuclides and that these materials may have contributed significantly to worker radiation exposure.[5]

Even if the contamination of the enrichment plants is accepted, the vast majority of the uranium, which is non-fissile uranium-238, would have to be disposed of as a waste. Proponents of nuclear power since the 1950s have dreamed that uranium-238 would be converted to fuel in "breeder reactors" which would use plutonium as a fuel, but make even more from uranium-238 – an energy system that was described as a "magical" energy source for that reason by Alvin Weinberg, the first director of Oak Ridge National Laboratory.

But despite $100 billion of expenditures (1996 dollars) worldwide, the combination of reprocessing and breeder reactors has never been commercialized.[6] In fact breeder reactors have operated so erratically – some well, some poorly – that there is no realistic prospect of significant use of commercial breeders for decades. So far as reprocessing is concerned, France, which operates the most efficient of the world's commercial reprocessing plants, spends about two cents more for every kilowatt-hour generated from MOX fuel, compared to uranium fuel.

Reprocessed uranium would add to the vast amounts of depleted uranium that has been generated as a result of enriching uranium for reactor fuel. Like the United States, France has not solved either problem. In recent years, there have been calls for disposing of depleted uranium as a Class A low-level radioactive waste in shallow land burial, even though such disposal would create long-term radiation doses greatly in excess of present-day radiation protection standards.[7] Disposal of reprocessing-derived uranium would be even worse, because it has a greater radioactivity per unit mass.

When radioactivity and biological impacts are taken into account, depleted and reprocessing-derived uranium would have to be disposed of in a deep geologic repository, as is transuranic waste. This would add to the burdens of waste disposal that have not yet been solved in any country.

Deep geologic repository

Finally, France will still need a deep geologic repository for its high-level and transuranic waste. Its repository program has faced public opposition not much different from that in the United States. For instance, France, like the United States, had planned to characterize two different repository rocks, including one in granite. When the names of the possible granite sites were announced, the public uproar caused the second repository site to be abandoned in 2000[8], much as the U.S. granite sites were abandoned under pressure in 1986. An earlier attempt to characterize a repository had to be abandoned in the face of militant opposition from farmers who raised gourmet chickens ("poulets de Bresse") in the region.[9]

Like the United States, France is characterizing just one repository, which continues to face significant technical and political issues.

Accident and security risks

France is rightly proud of its culinary and viticultural traditions. As noted above, a part of the militant opposition to a nuclear waste repository was motivated by farmers who supply gourmet chickens designed to please particular Parisian palates. Yet, little attention has been given as to what would happen if there were to be a severe accident releasing large amounts of radioactivity, of the same order of magnitude as Chernobyl. Such an accident is less probable in France. Its reactors are of a different design, for one thing. Yet, while the mechanisms would be different and the probability is likely lower, the occurrence of such an accident would irreparably harm the finest traditions of the country. When I debated a French proponent of nuclear power in Paris in the 1990s and pointed this out, much of the audience was shocked at this realization.

Despite a larger use of plutonium fuel than any other country, France has a huge stock of surplus plutonium. As of 2005, 81 metric tons of plutonium were stockpiled at La Hague, of which about 51 metric tons belonged to France.[10] France does not have much scope to expand its plutonium fuel consumption, since only eight more reactors (for a total of 28) are suitable for using MOX fuel up to 30 percent in the reactor core. The plutonium is stored in tens of thousands of containers. There is a risk of terrorist attacks either on the plutonium stocks or on the liquid high level waste tanks.

There are also proliferation risks, the most notable of which relates to Japan. France reprocesses Japanese spent fuel and has helped Japan to build and commission a large commercial reprocessing plant, Rokkasho-mura.[11] Japan

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has had ambitions to use MOX fuel in its reactors for many years, but to date has not yet used any due to a host of problems. Its breeder reactor program has also been plagued with difficulties, including a sodium fire at its Monju demonstration plant in 1995.

The temptation to weaponize stocks of surplus plutonium separated in commercial reprocessing plants was most dramatically expressed when Ichiro Ozawa, the leader of Japan's Labor Party, opined in 2002 that Japan could use its commercial nuclear assets to make thousands of nuclear weapons if China got too powerful and "inflated."[12]

Overall, the security problem of surplus plutonium continues to mount. There were about 250 metric tons of surplus commercial separated plutonium around the world in 2005, with the British stock being even larger than the French – at 107 metric tons. Britain continues to reprocess though it does not have even a single reactor that is using MOX fuel. One of its two reprocessing plants suffered a large internal leak of highly radioactive material and has been closed for two years.

The Keystone Center Joint Nuclear Fact-Finding (NJFF), which included nuclear industry representatives, had some rather stark cautions about reprocessing risks and about the promotion of reprocessing by the Bush administration's Global Nuclear Energy Partnership (GNEP):

> *While the NJFF agrees with several premises of the GNEP, the program is not a strategy for resolving either the radioactive waste problem or the weapons proliferation problem. The NJFF group agrees with the following proliferation concerns that GNEP attempts to address:*
>
> - All grades of plutonium, regardless of the source, could be used to make nuclear explosives and must be controlled.
> - Reprocessing poses a problem in non-weapons states Widespread use of mixed-oxide fuel by both weapons states and non-weapons states is similarly troublesome.
> - Even in the weapons states, plutonium must be protected, and one should not increase stocks of plutonium in sep rated or easily separated forms such as mixed-oxide fuel.
>
> *The NJFF participants believe that critical elements of the GNEP are unlikely to succeed because:*
>
> - GNEP requires the deployment of commercial scale reprocessing plants, and a large fraction of the U.S. and global commercial reactor fleets would have to be fast reactors.
> - To date, deployment of commercial reprocessing plants has proven uneconomical.
> - Fast reactors have proven to be uneconomical and less reliable than conventional light-water reactors.
>
> Although it is not its aim, the GNEP program could encourage the development of hot cells and reprocessing R&D centers in non-weapons states, as well as the training of cadres of experts in plutonium chemistry and metallurgy, all of which pose a grave proliferation risk.[13]

French nuclear decision-making

France made the decision to go massively for nuclear power in 1973, when the oil crisis pointed up the vulnerability of its electricity system, which used oil for nearly 40 percent of its generation. While nuclear power allowed France to essentially eliminate oil from its electricity sector (it has been around two percent in recent years), there was not much open debate about the merits of heavy reliance on nuclear. The opposition to nuclear power was largely overridden with rhetoric of energy independence. But in fact France imports all of its uranium – only the nine percent or so of its nuclear electricity that is derived from plutonium can reasonably be described as using domestic fuel. And it is as dependent as ever on oil imports because of the rising use in the transportation sector.

France's less than adequate public checks on the massive nuclear expansion was made much easier by the fact that it had just one electric utility, Electricité de France (EdF), that was 100 percent government-owned. Even today EdF is over 80 percent government-owned. Cogéma, the reprocessing company, was also 100 percent government-owned. Today it is part of the conglomerate AREVA, which is more than 80 percent French government-owned.

Conclusions

The French model of imposing added costs on its ratepayers and taxpayers, of polluting the oceans in the face of protests from neighboring governments, and of accumulating vast amounts of domestic and foreign surplus plutonium hardly seems like a model for the United States or anyone else to follow. As noted in the accompanying articles, there is a reasonable, clear path to a renewable energy-based electricity sector that does not involve the headaches and risks of nuclear power, which is, moreover, expensive. There is not a shortage of low to zero-CO_2 energy sources. There are two limitations that are much more critical:

- The amount of time we have to address the problem of drastically reducing CO_2 emissions is small and shrinking.
- The amount of money is limited, so it should be applied where it will do the most good in the shortest period of time.

Nuclear plants will take many years to build. As noted in the article on nuclear power plant costs (page 1), there is a reasonable prospect that intermediate-scale solar power may make nuclear power economically obsolete in a decade or less, especially if public policies would be designed to favor it in that period instead of nuclear power.

France fixed the problem of its dependence on oil for electricity generation by going massively nuclear, but in doing so, it opened a whole other can of worms. Following in France's nuclear footsteps is not nearly as appetizing as the nuclear proponents have made it out to be. Even the French are having second thoughts. Less than 31 percent of the French public favor nuclear energy as a response to today's energy crisis. 54 percent are now opposed to investing 3 billion euros in the construction of a new reactor, while 84 percent favor the development of renewable energy.[14] But the French are stuck and will be for some time, since they have dug a much deeper nuclear hole for themselves proportionally than the United States.

SEE **FRANCE'S NUCLEAR FIX?** ENDNOTES ON PAGE 8

FRANCE'S NUCLEAR FIX? FROM PAGE 7

Endnotes

1. IEER's website has a considerable number of materials relating to nuclear power in France. Under Publications, see "Low Carbon Diet without Nukes in France," "Cogéma: Above the Law", and "Plutonium End Game." Under ***Science for Democratic Action***, see Vol. 9, No. 2; Vol. 13, No. 4; and Vol. 14, No. 2.
2. "Qu'y-a-t-il entre le déchet et l'environment" web site of the CEA at www.cea.fr/var/plain/storage/original/application/fda10c807ffc6bb4da51cb04aaded70f.pdf
3. This fact was revealed during the discussion following the presentation of Alan Hanson, Vice-President, AREVA to the Keystone Center Nuclear Power Joint Fact-Finding, which was published in June 2007. Arjun Makhijani was a co-presenter.
4. Joby Warrick, "Paducah Workers Sue Firms Class Action Cites Radiation Exposure, Seeks $10 Billion," *Washington Post,* September 4, 1999.
5. PACE (Paper, Allied Industrial, Chemical and Energy Workers International Union) and University of Utah, *Exposure Assessment Project at the Paducah Gaseous Diffusion Plant,* December 2000.
6. For details of the failure to commercialize plutonium, see Arjun Makhijani, *Plutonium End Game,* Institute for Energy and Environmental Research, Takoma Park, Maryland, 2001.
7. Arjun Makhijani and Brice Smith, *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES,* Takoma Park, MD: Institute for Energy and Environmental Research, November 24, 2004, redacted version published in February 2005 (on the Web at www.ieer.org/reports/du/lesrpt.pdf); And, Arjun Makhijani and Brice Smith, *Update to Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES* by Arjun Makhijani, PhD. and Brice Smith, Ph.D. based on information obtained since November 2004, Takoma Park, MD: Institute for Energy and Environmental Research, July 5, 2005, redacted version published August 10, 2005 (on the Web at www.ieer.org/reports/du/LESrptupdate.pdf).
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10. Keystone Center, *Nuclear Power Joint Fact-Finding,* Keystone, CO, June 2007, page 18. On the Web at www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf.
11. See "Rokkasho: A Troubled Nuclear Fuel Cycle Complex" by Masako Sawai in SDA Vol. 9, No. 4. On the web at www.ieer.org/sdafiles/vol_9/9-4/.
12. Reuters. *Japanese nukes could counter China* - politician, April 6, 2002. Dateline: Tokyo. On the Web at www.nci.org/02NCI/04/japan-articles.htm. Viewed on December 2, 2007.
13. Keystone Center, p. 18.
14. www.actu-environnement.com/ae/news/1872.php4

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A Reliable Renewable Electricity Grid in the United States

BY ARJUN MAKHIJANI, Ph.D.[1]

Can an electricity grid consisting entirely of renewable energy sources be made at least as reliable as the one we have today in the United States? A lack of a clear answer to this question has, until now, persuaded many thoughtful people that nuclear power should be "left on the table" as we phase out the use of fossil fuels, especially coal, to generate electricity due to climate change concerns.

Today, coal is the fuel for about half of U.S. electricity consumption. Nuclear and natural gas fuel about 19 percent each. Almost all the rest comes from hydropower, geothermal and wood waste. Wind and solar contribute less than one percent, almost all of it from the former. Electricity generation is overwhelmingly centralized, with about 95 percent of it being generated in large power plants.

There is no question that the resources exist for a transition to a full renewable electricity sector. Just the land-based wind power resources of the top 20 states are about two-and-a-half times the entire U.S. electricity generation. They are roughly equivalent in thermodynamic terms to all of the oil output of OPEC (Organization of Petroleum Exporting Countries) combined. There are additional wind energy resources offshore. Solar energy resources on just one percent of the land area of the United States, converted to electricity at 20 percent efficiency, are three times larger than wind.

Until recently, economics has been a central problem with renewable energy compared to fossil fuels. But this does not take into account the costs of emitting CO_2, which is creating severe disruption of the Earth's climate. And for well over a decade, wind-generated electricity has been as economical as nuclear, though not as economical as coal without any cost attached to CO_2 emissions.

As noted in the accompanying article on nuclear power cost on page 1, solar photovoltaic electricity costs are declining rapidly, while nuclear electricity cost estimates are rising. Intermediate-scale and large solar PV (photovoltaic) costs are about the same as the cost of electricity generated at peak times using single-stage natural gas turbines. Solar PV costs are expected to decline to 10 cents per kWh or less in about a decade.

Further, solar thermal power plants are now beginning to be deployed on a large-scale after a hiatus of about two decades.[2] For instance, PG&E, a large Northern California utility has agreed to purchase 553 megawatts of power from a solar thermal power plant to be built in the desert areas of Southern California. It plans to expand its solar thermal power purchases to 1,000 MW by 2020, under a state mandate.[3]

Intermittency

The main issue with wind and solar is intermittency. Solar energy is by definition a daytime source, and its availability varies by season, the more so at northern latitudes. Wind energy is also intermittent; it can vary greatly from one hour to the next and from day to day, in addition to having seasonal patterns. But intermittency is not an obstacle to achieving a reliable renewable electricity sector if renewables are added to the grid in a planned manner, with due attention to geographic and other factors as well as to standby capacity.

At present, about 0.7 percent of U.S. electricity supply comes from wind and solar energy, almost all of it from wind. Increasing wind energy to 10 percent of electricity generation or more while maintaining reliability has been shown to be feasible in Europe, as for instance in Denmark, which gets about 20 percent of its electricity from wind. Increasing wind-generated electricity beyond a few percent requires additions to standby capacity in order to maintain the reliability of the electricity system.

Development of wind resources in a manner that takes advantage of the large areas over which the resource is available provides a great advantage in that it reduces the time during which aggregate generation from wind energy is low. Studies have found that the costs of wind energy integration into the grid can be kept modest or small up to fairly high levels of penetration if geographic diversity is taken systematically into account as one design factor in the utilization of the resource.

For instance, a study commissioned by the Minnesota state legislature found that the ability to forecast available wind resources was considerably improved when the geographic diversity of the wind generation was increased. Dispersing wind turbines not only reduces the time during which no or low wind energy is available, it also improves the reliability of forecasting upon which reserve capacity requirements are based. One conclusion was that the reserve requirements for Minnesota's electricity system would increase from 5 percent with no wind generation to just over 7 percent with 25 percent of the generation coming from wind. This is a rather modest cost. There is ample reserve capacity in the U.S. electricity system to meet such additional reserve requirements.

A new study done at Stanford University came to the even stronger conclusions. It examined wind farms spread over a five state area — New Mexico, Colorado, Kansas, Oklahoma, and Texas:

> It was found that an average of 33% and a maximum of 47% of yearly-averaged wind power from interconnected farms can be used as reliable, baseload electric power. Equally significant, interconnecting multiple wind farms to a common point, then connecting that point to a far-away city can allow the long-distance portion of transmission capacity to be reduced, for example, by 20% with only a 1.6% loss of energy.

The fraction of reliable capacity can also be increased by coordinating additions to capacity with solar energy. Wind often blows at night, making it very advantageous to join

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wind and solar development in a way that would reduce costs for the same reliability.

Overall reliability planning

Whatever approach is chosen for future electricity development, planning at various levels – local, state, regional, and federal – is essential for maintaining reliability, not to speak of improving it.

Wind and solar can and should be coordinated with hydropower and natural gas standby. At prices in excess of $6.50 per million Btu of natural gas, as at present, it is economical to use natural gas as a standby for wind power. As solar PV costs decline to the level of about 10 cents per kWh (that is by about 50 percent from the present level of about 20 cents per kWh), natural gas standby can also be economically used for solar electricity. No additional natural gas capacity is needed, since a large surplus of natural gas capacity already exists in the country. Electric utility and independent generator natural gas capacity utilization was under 19 percent in 2006. This is because a huge amount of natural gas capacity was built in the 1990s and the first years of the present decade under the assumption that natural gas prices would remain low. But they have not. This economic error provides a great opportunity to both minimize the use of natural gas and rapidly increasing the fraction of solar and wind energy in the electricity system and maintaining the overall reliability of the system. This conclusion needs to be translated into specifics for the development of renewable energy in each grid that is operated in the United States, and overall for the three grid regions in the lower 48 states – the Eastern Interconnect, the Western Interconnect, and the Texas grid known as ERCOT (Electric Reliability Council of Texas).

With appropriate planning and policies regarding efficiency, reserve capacity requirements, coordination of solar and wind development to increase reliability, there should be no problem in increasing the proportion of renewables plus combined heat and power from about 5 percent at present to about 40 percent by 2030 (not including hydropower). A faster transition is also possible, given the right coordination and policies.

Beyond 15 to 20 years, significant storage capacity and some baseload capacity that operates on energy sources that are under the operator's control would be required to fully replace coal and nuclear. It is possible that the need for such capacity could be minimized through building a "smart grid" so that certain appliances in homes and businesses operate when there is renewable electricity available. But whatever the approach, reliability will require significant energy storage and baseload components.

The first thing to note is that there are fifteen to twenty years to develop and deploy such technologies on a significant scale. Sources of baseload or quasi-baseload capacity include:

- Solid biomass, such as dried algae or high productivity aquatic plants
- Hot rock geothermal energy
- Solar thermal power plants with 12-hour energy storage

Combined heat and power, hydropower, and standby combined cycle plants operated using biogas would provide additional elements of reliability and flexibility.

There are a number of energy storage technologies that could be used, including:

- Compressed air storage in underground caverns
- Advanced stationary batteries
- Batteries in electric cars and/or plug-in hybrids that would be connected to the grid when the cars are parked – a system known as "vehicle to grid" (V2G) technology. V2G can be combined with intermediate and small-scale solar PV development. Google has begun exploration of this concept in collaboration with PG&E.

Compressed air storage has already been demonstrated. Stationary batteries suitable for storage, notably sodium sulfur batteries, have been developed. Tokyo Electric Power and American Electric Power inaugurated the first U.S. sodium sulfur battery demonstration project in Columbus, Ohio, in September 2007.[4] The batteries have also been tested in Japan.

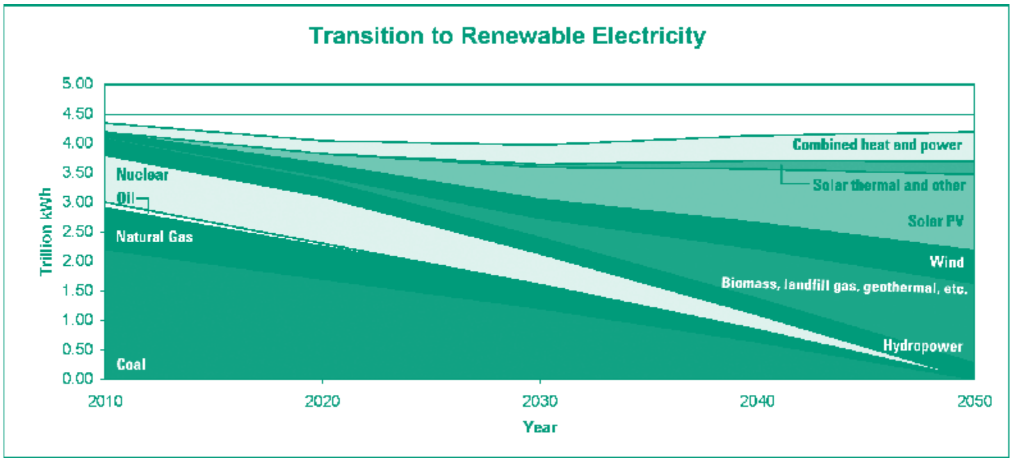
If public policy puts a suitably strong emphasis on plug-in hybrids and electric cars in the coming decade, there is every prospect that one or more electricity storage technologies will be commercialized as part of electric vehicle development. Electric cars or plug-in hybrids would make electricity storage even cheaper than stationary batteries, provided the batteries can be charged or discharged more times than is needed for the operation of the vehicle over the typical vehicle life of about ten years. Altairnano, a Reno, Nevada, company has already made lithium ion batteries that meet this test. They are being installed into an all-electric pickup truck by Phoenix Motorcars, Inc. in 2007. Such batteries are still too expensive, partly due to the newness of the technology and partly due to the small scale of manufacture.

A V2G system would be especially attractive as a form of electricity storage. Vehicles have a much larger installed power than the U.S. electricity system and, moreover, they are not in use over 90 percent of the time. A few percent of the vehicles plugged into the grid at any time and under the control of the grid operator could supply the electricity storage and power needed to maintain a reliable electricity grid.

Figure 1 shows one possible transition from the present fossil fuel and nuclear-dominated, centralized electricity sector to a distributed grid operating fully on renewable energy. Note that electricity demand remains about constant even as electric cars are introduced because homes and commercial buildings would be much more efficient. The inefficiency of present day buildings and the equipment in them is very great. Incandescent lamps, the most common kind, convert only about 3 percent of the electricity into visible light. Compact fluorescent lamps are three to four times as efficient. Light emitting diodes are

SEE A RELIABLE RENEWABLE ELECTRICITY GRID ON PAGE 11, ENDNOTES PAGE 11

Figure 1



Source: IEER

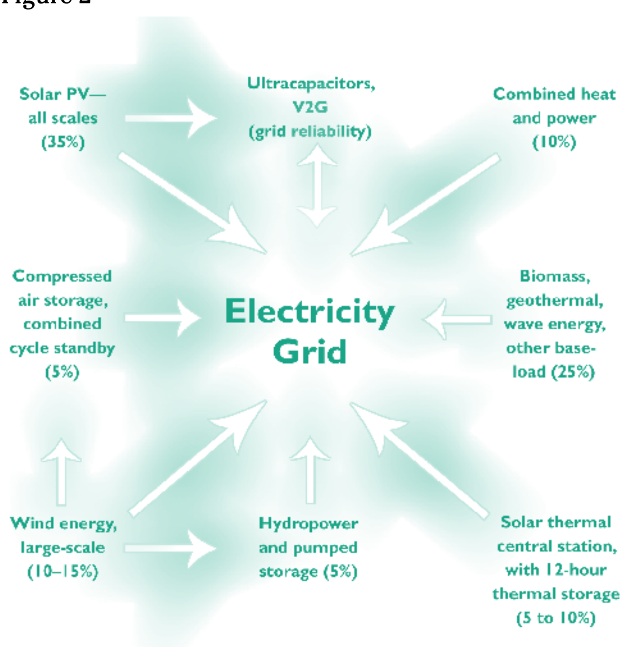
A distributed grid, such as that shown in Figure 2, would be at least as reliable and far more secure that the present centralized grid. For instance, if events similar to the ones that have led to major blackouts in the past (New York 1965, Eastern United States 2003) were to occur, the whole system would not go down – local electricity sources and storage devices would still be supplying a significant fraction of the requirements. Further, a terrorist attack on one or more critical points of the transmission infrastructure would also not disrupt the entire system. By virtue of greatly reducing the impact of such an attack, the electricity system would be much less likely to be attacked.

more efficient than that. New lighting technologies, such as optical fibers that combine sunlight and electrical light sources to maintain constant interior lighting, are in the process of being commercialized. Similar opportunities exist in other areas of electricity use.

With a reasonable approach to efficiency and appropriate policies to coordinate the development of renewable energy sources and investments in energy storage technologies, a completely renewable electricity grid is not only technically feasible, it is the most desirable from an ecological and health standpoint. The overall cost of electricity services would remain about the same proportion of GDP as today. But there would be greater investment in efficiency relative to new generation than is typical at present.

Figure 2 shows a schematic of a fully renewable electricity grid. It is being republished here for convenience (it was also published in SDA Vol. 15, No. 1).

Figure 2



Source: IEER

Conclusion

There are many who have claimed that nuclear power "should be on the table" because a reliable electricity grid will require it. But this assertion has not been accompanied by any rigorous analysis to show that new nuclear power plants are actually needed. This analysis shows that neither coal nor nuclear power is needed for a reliable and secure electricity system, though it will likely take three to four decades to accomplish a complete transition to a renewable electricity system. Such a transition needs to be carefully carried out with due attention to efficiency, diversity of renewable supply, standby capacity, and storage, with the last being important at high levels of penetration. The bottom-line is clear: coal and nuclear can and should be phased out from the electricity sector simultaneously.

Endnotes

1. This article is based on Arjun Makhijani, *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy,* IEER Press and RDR Press, 2007, unless otherwise stated, especially the wind and solar energy sections in Chapter 3 and Chapter 5. References can be found there.
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3. David R. Baker, "PG&E Embraces Solar Thermal Power Technology," *San Francisco Chronicle,* November 5, 2007, on the web at www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2007/11/05/BUBTT5KM2.DTL.
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Yucca Mountain, Nevada: *A Bad Repository Choice*

BY ARJUN MAKHIJANI, Ph.D.[1]

The nuclear industry has been quick to proclaim that a "nuclear renaissance" is occurring, or is at least in the offing, though not a single new reactor has been ordered at the time of this writing (mid-November 2007).

The industry has been correspondingly slow to say what will happen to all the spent fuel that will be generated by these new power plants, though the general assumption is that the government will take it away from reactor sites and do something with it – store it at its own sites (such as Savannah River Site in South Carolina), reprocess it (a variety of sites have been proposed), or put it in the proposed deep geologic repository at Yucca Mountain, Nevada.

Storage and reprocessing do not obviate the need for a repository; therefore the availability of Yucca Mountain (and/or some other yet-to-be-named repository) remains a consistent underlying theme of the much-vaunted "nuclear renaissance."

Yet, Yucca Mountain is in deep trouble (so to speak) for very good reasons. Though I have written a rather large volume of words on the topic,[2] it may serve as a useful reminder in the current context to summarize why Yucca Mountain is an unsound repository location. Indeed, in my opinion, it is the worst repository site that has been investigated in the United States. I will focus on the problems of Yucca Mountain in relation to some important criteria by which a sound repository program can be judged.

Repository standards and future radiation doses

Maximum estimated radiation doses to future generations at the time of peak dose should be within the general limits that we set for protecting our own generation. If they are expected to be much higher, then the repository will not meet the test of inter-generational equity. Yucca Mountain fails this test miserably.

Peak doses to the most exposed people are expected to be much higher than the current norms of 10 to 25 millirem per year incorporated in U.S. Environmental Protection Agency (EPA) radiation protection standards relating to nuclear facilities. Table 1 shows the various risks associated with the proposed EPA standard and with the peak doses (median and 95th percentile) estimated by the U.S. Department of Energy (DOE) in its 2002 Environmental Impact Statement.

The EPA's draft standard would limit radiation dose to 15 millirem per year for the first 10,000 years. Beyond that, it would allow half the affected people to get more than 350 millirem per year and half less. This is far in excess of present-day radiation protection norms for the general public. The average population fatal cancer risk (males and females combined) at 350 millirem per year over a lifetime is about 1 in 71, which is over 20 times the risk of a 15 millirem per year limit and over a hundred times greater than EPA's general goal of limiting lifetime fatal cancer risk to 1 in 10,000.

The draft EPA standard would allow five out of every hundred people to get radiation doses of 2,000 millirem per year or more. *At this level, the lifetime fatal cancer risk for females (over a 70-year exposure period) would be about 1 in 10. The corresponding cancer incidence risk would be 1 in 5. These last numbers are not much different than the risk of shooting oneself while playing Russian roulette – except here the present generation would be forcing it on those far in the future who had no part in our decisions.*

The Department of Energy (DOE) made its own estimates in its Final Environmental Impact Statement on Yucca Mountain. The DOE estimated that the 95th

Table 1: Projected radiation doses and cancer risks -- Yucca Mountain
Using draft EPA standard and DOE estimated peak dose estimates

	Draft EPA standard			DOE peak dose estimates (see note)	
	First 10,000 years	Median after 10,000 years	95th percentile value after 10,000 years	Median value	95th percentile value
Annual exposure, effective dose equivalent, millirem/year	15	350	2,000	140	600
Lifetime dose over 70 years, millirem	1,050	24,500	140,000	9,800	42,000
Average lifetime fatal cancer risk (males and females), expressed as 1 fatality among XXX exposed	1,656	71	12	177	41
Lifetime fatal cancer risk for females, expressed as 1 fatality among XXX exposed	1,394	60	10	149	35

Note: The DOE estimates that there will be many peaks of doses due to future climatic variations. These figures represent the largest estimated values of the peak dose. They are estimated to occur hundreds of thousands of years from the present.

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percentile of the peak dose would be about 600 millirem (see Figure 1). The lifetime fatal cancer risk to females from this dose would be about 1 in 35 (rounded). The "95th percentile" part of this means that five percent of women exposed to Yucca Mountain pollution at that time would be at greater risk than 1 in 35, while 95 percent would be at lower risk. Cancer incidence risk would be about double this value or about 1 in 17 (rounded).

EPA draft standard vs. DOE peak dose estimate

The U.S. Environmental Protection Agency is responsible for setting a limit for how much radiation the public can be exposed to by the proposed nuclear waste repository at Yucca Mountain. The EPA's draft standard would limit radiation dose to 15 millirem per year for the first 10,000 years. Beyond that, it would allow half the affected people to get more than 350 millirem per year and half less. A final standard has not been issued as of this writing (late November 2007).

In a federally-mandated environmental impact statement, the U.S. Department of Energy made projections for future radiation doses from the Yucca Mountain repository. The DOE estimated that median peak dose would be approximately 140 millirem per year and would occur roughly 400,000 to 500,000 years after repository closure.

Figure 1. Mean and 95th-percentile doses from Yucca Mountain spent fuel disposal estimated by the DOE

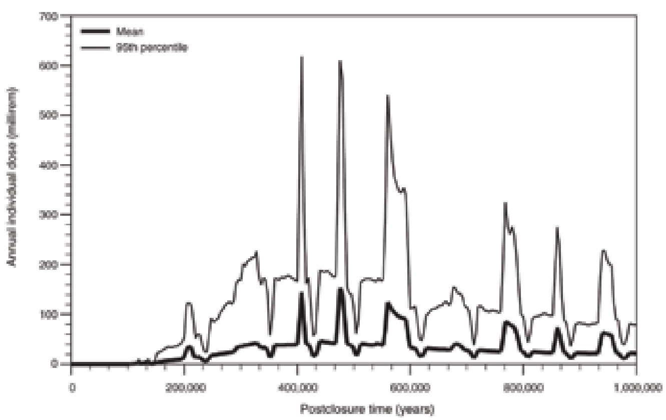
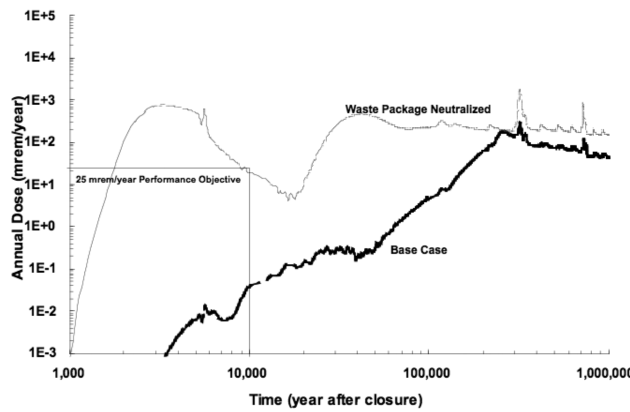


Figure 1 taken from page 5-26 of Volume 1 of the Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, February 2002. On the Web at http://www.eh.doe.gov/nepa/eis/eis0250/eis0250index.html.

Characteristics of the Yucca Mountain geologic setting

A minimum requirement of the geologic setting should be that, when the containers fail and begin to leak (and it is a question of when not if), the geology of the repository should be conducive to retarding the movement of the radioactive materials and to preventing most of them from reaching groundwater or surface water. Materials produced by the DOE for the Nuclear Waste Technical Review Board show that the Yucca Mountain rock is practically useless in holding back radioactive materials. Almost the entire functioning of the repository depends on the engineered barriers, mainly the metal containers. Unless they function as predicted by the DOE, Yucca Mountain will not meet the draft EPA standard even for the first ten thousand years. And since these containers will eventually rust, all calculations show that the peak dose will greatly exceed EPA's norms for radiation protection today.[3]

Figure 2: DOE Estimates of Yucca Mountain Total System Performance ("Base Case") and Performance without the Waste Package ("Waste Package Neutralized")



Note on y-axis figures: "1E-3" signifies 10^{-3} which also can be written 0.001. Similarly, 1E+5 = 10^{+5} = 100,000 and 1E+0 = 10^{0} = 1.

The graph in Figure 2 was prepared in 1999 by the DOE for the Nuclear Waste Technical Review Board (NWTRB), an advisory board created by Congress to oversee the Yucca Mountain Project. The Board had requested that the DOE evaluate each element in the geologic isolation system for its contribution to overall performance in meeting the then-assumed limit of 25 millirem per year for the first 10,000 years of repository operation. (No dose limit was proposed beyond that time. Later, a federal court invalidated the standard first proposed by EPA mainly because it too did not look beyond 10,000 years.

The DOE graph, supplied to the NWTRB as part of its request, shows that if the entire system were in place and performed as modeled, the dose limit of 25 millirem would be met rather easily for the first 10,000 years, though it would eventually be exceeded by a considerable margin at 100,000-plus years after repository closure. However, it shows that if the "waste package," which consists primarily of a huge metal container made of a special nickel-based alloy called C-22, degrades quickly (in hundreds of years or a few thousand years), the peak dose would rapidly increase to nearly 1,000 millirem well within 10,000 years, which is greatly in excess of any standard that has been proposed for that time period.

The waste package

As a result of the above, the reliability of the DOE estimate of the performance of the metal containers

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becomes critical to the performance of the repository. If the containers do not perform as estimated in the DOE's "base case" or close to it, the repository will be a terrible failure. As a result, a high confidence in the performance of these containers is essential. However, current knowledge does not admit such confidence. On contrary, basic as well as Yucca Mountain-specific considerations indicate that the waste package may degrade rather rapidly.

DOE's silver-bullet container may turn out to be a dud.

The Yucca Mountain geologic environment is oxidizing; it also has some humidity. The waste will be hot for an extended period and it will heat the surrounding materials and rock. This combination of heat, humidity, and oxygen is a recipe for rust. The rate of rusting in such an environment is a matter of some debate. The containers could, under some circumstances, corrode much faster than 10,000 years. Indeed, in some circumstances the containers may corrode in decades. Further, the metal alloy proposed for the containers is new – there is no long-term experience with its performance. As a result, there is a real possibility that DOE's silver-bullet container may turn out to be a dud. Since the repository location itself is not protective, a failure of the containers would lead to serious pollution of the groundwater and render it useless in an area where water is very scarce.

Since there is a large and growing amount of spent fuel to be disposed of, jamming a large amount of it into Yucca Mountain is a temptation. However, this would result in high temperatures in the repository conducive to rapid corrosion.[4] The DOE has so far refused to specify a repository design, though such a specification is an essential part of a minimally complete license application. The license application was due in 2002 and has not yet been filed. The DOE has stated that it will be filed in mid-2008.

Reliance on a single element of a complex system as the only guarantee of performance is risky under the best of circumstances. For instance, commercial passenger aircraft that have two engines are required to be able to operate in emergencies on only one, even though there is vast experience with jet engine reliability and performance. Redundancy is even more essential in a system of an unprecedented nature whose performance is very difficult to estimate under the best of circumstances due to the long times involved.

Redundancy in repository design means that if the containers fail, the rock should adsorb the radionuclides and prevent or greatly retard their migration into groundwater. By this criterion, Yucca Mountain is a near-total failure, since the performance of all waste isolation components taken together but without the waste package does not amount even to the proverbial hill of beans. That is the central message of Figure 2. The waste could be put in almost any geologic location with equal or better performance, since the performance of the Yucca Mountain host rock is next to nil. This is shown in Figures 3 and 4, also taken from the set produced by the DOE for the NWTRB.

Figure 3 shows that if the rocks surrounding the waste disposal zone ("unsaturated transport barrier") were removed, but the waste package performed as estimated in the "base case," there would be essentially no change in the performance of the system. In other words, the volcanic tuff at Yucca Mountain is practically useless in holding back the radionuclides once the waste package fails. Figure 4 shows that the same is true of the saturated zone. That is, once the waste reaches the groundwater, there will be no mechanism that would significantly reduce dose.

Figure 3: Unsaturated Yucca Mountain Transport Barrier Removed

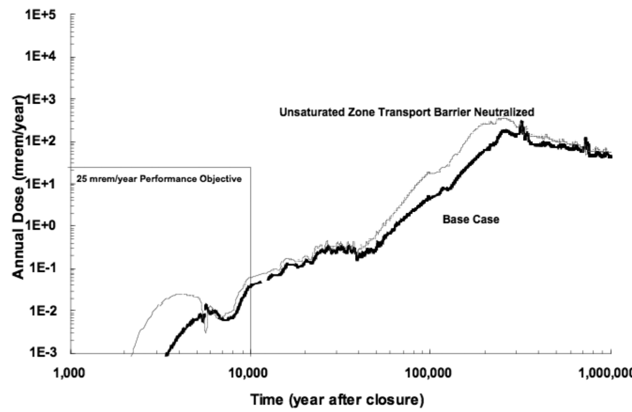
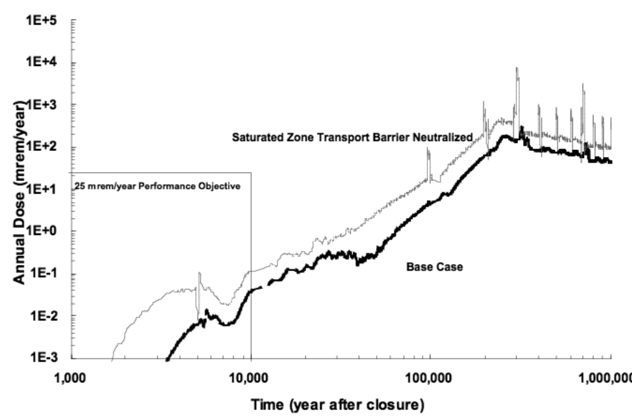


Figure 4: Saturated Yucca Mountain Transport Barrier Removed



Source for figures 2–4: U.S. DOE Office of Civilian Radioactive Waste Management, "NWTRB Repository Panel meeting: Postclosure Defense in Depth in the Design Selection Process," presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999

Water resources

The performance of the repository in relation to groundwater matters more for Yucca Mountain because there are no surface water resources in that general region of Nevada. The only water source in the area is an aquifer

SEE **YUCCA MOUNTAIN** ON PAGE 15, ENDNOTES PAGE 15

that is currently being used in Amargosa Valley, just 20 miles downstream from Yucca Mountain.

The scarcity of water ensures two things. First, if the containers don't hold up, there will be little dilution and the water will become very polluted. Second, the lack of alternative water resources makes it likely that future residents may unknowingly use the polluted groundwater.

This is not a new finding. About a quarter of a century ago, the DOE had commissioned the National Research Council of the National Academy of Sciences to prepare a report that was supposed to guide it in its search for a sound repository. That report, published in 1983, four years before the 1987 legislation that restricted site characterization to Yucca Mountain, showed that radiation doses due to high-level radioactive waste disposal at Yucca Mountain could be very high, in large measure due to the scarcity of water.[5] To the best of my knowledge, the DOE does not appear to have used this report to substantially guide its repository program, though it paid for it.

The evidence shows that Yucca Mountain is an unsound repository program that should not be pursued further.

Conclusions

The evidence shows that Yucca Mountain is an unsound repository program that should not be pursued further. If there were a reasonably protective radiation standard – one that protected future generations to the time of peak dose according to present-day EPA norms – Yucca Mountain could not be licensed.

Security, health, safety, and environmental considerations indicate that the Yucca Mountain program should be scrapped and replaced by a repository program based on sound science and public health protection criteria. It should be managed not by the DOE but by an institution that does not itself generate high-level waste or spent nuclear fuel. The same considerations also point to the need for Hardened On-Site Storage (HOSS) of spent fuel as an interim step.[6]

A "nuclear renaissance" based even implicitly on the availability of Yucca Mountain for spent fuel from new reactors is founded on wrong-headed thinking similar to that of the 1950s that assumed waste disposal would be a problem that could be managed relatively easily. Based on that kind of thinking, the DOE, in the early 1980s, entered into contracts with nuclear utilities to begin take possession of spent fuel from them and start disposing it of in a deep geologic repository by January 31, 1998. That deadline has long since passed and the DOE has not even applied for a license.

The opening of Yucca Mountain, if it ever happens, appears more remote than ever for a host of reasons. Because the first repository characterization has been a costly failure so far by every reasonable measure of contract performance, assuming that the government would take responsibility for nuclear waste from new reactors decades from now may well add folly to the error of having created so much waste in the first place. Why then are so many so eager to pursue nuclear power, with its concomitant embrace of nuclear waste, when we don't need the headaches of nuclear to completely eliminate fossil fuel use from the U.S. economy?[7]

Endnotes

1. Based on "Comments of Dr. Arjun Makhijani on Yucca Mountain and the draft EPA standard submitted for the record of the Senate Environment and Public Works Committee hearing on the 'Examination of the Licensing Process for the Yucca Mountain Repository'," October 31, 2007, and on IEER comments on the EPA draft standard for Yucca Mountain, November 2005, on the Web respectively at www.ieer.org/comments/waste/yucca071031.html and www.ieer.org/comments/waste/yuccaepa.pdf
2. See IEER's web site, specifically www.ieer.org/webindex.html#waste.
3. For instance, the maximum routine exposure to the public from a single nuclear fuel cycle facility from all pathways, including air, water, and food, is limited to 25 millirem per year to any organ (except 75 millirem to the thyroid) or to the whole body. (40 CFR 190.10(a))
4. Paul P. Craig, "Rush to Judgment at Yucca Mountain," *Science for Democratic Action, Vol. 12, No. 3, June 2004,* on the Web at www.ieer.org/sdafiles/12-3.pdf
5. Waste Isolation Systems Panel, Board on Radioactive Waste Management, National Research Council. *A Study of the Isolation System for Geologic Disposal of Radioactive Waste.* Washington, DC: National Academy Press, 1983.
6. See www.ieer.org/comments/waste/yuccaalt.html for a discussion of HOSS.
7. For a roadmap to a nuclear-free renewable energy economy, see Arjun Makhijani, *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy,* IEER Press and RDR Books, 2007. On the Web at www.ieer.org/carbonfree/.

WAY TO GO, DR. EGGHEAD!

IEER's President Arjun Makhijani (a.k.a. Dr. Egghead) received two great honors the past year.

First, Ploughshares Fund honored Arjun as one of nine "Ploughshares Heroes," those who "make our world safer and our families more secure by their individual and collective actions."

Second, Arjun was elected a Fellow of the American Physical Society. Here are excerpts from the two award citations.

Congratulations, Arjun, on two well-deserved awards.

Dear Dr. Makhijani,

I have the honor of informing you that the Council of the American Physical Society at its November 2007 meeting acted favorably on your nomination for Fellowship in the Society upon the recommendation of the Forum on Physics & Society. As you may know, election to Fellowship in the American Physical Society is limited to no more than one half of one percent of the membership. Election to APS Fellowship is recognition by your peers of your outstanding contributions to physics.

The citation, which will appear on your Fellowship Certificate, will read as follows:

"For his tireless efforts to provide the public with accurate and understandable information on energy and environmental issues."

—Excerpt from the November 19, 2007, letter to Arjun Makhijani from Alan Chodos, Associate Executive Officer of the American Physical Society

Note from Arjun Makhijani: I am deeply grateful for this extraordinary recognition. Much of the credit should be shared with the staff of IEER, who, over the years, have contributed so greatly to the integrity and accessibility of my work. I would also like to thank Kitty Tucker and Bob Alvarez, who introduced me around 1980 to the idea of work on the health and environmental effects of nuclear weapons production and testing.

And thanks to the Ploughshares Fund, in turn a Hero for IEER. Its consistent and generous support has enabled the long-term work that underlies our common victories for health, environment, and disarmament.

Arjun Makhijani, Ploughshares Hero

"In a real, practical sense," says Arjun Makhijani, "the first arms control treaty was an environmental one." Public protests in the 1950s about contamination of breast milk and babies' teeth with strontium-90 were central to the 1963 Partial Test Ban Treaty. It is no surprise, then, that the near-total cessation of new nuclear weapons production in the U.S. over the past two decades has come largely in response to the people and organizations who have challenged the production and testing of nuclear weapons on the basis of the environmental devastation they cause.

Makhijani himself is a key reason these challenges have succeeded. A physicist whose Institute for Energy and Environmental Research conducts its own rigorous independent investigations into nuclear programs and their environmental liabilities, Makhijani has trained hundreds of activists who live in the shadows of nuclear weapons facilities, providing them with everything from a basic grasp of nuclear physics to more advanced understandings needed to engage the weapons establishment with sound, scientific arguments.

"It is a remarkable fact of nuclear weapons history that every nuclear weapon state has first of all harmed its own people in the name of national security," he says. From leaking underground waste tanks at Hanford in Washington, to radioactive tritium contaminating the Savannah River in South Carolina and Georgia, to new threats of environmental damage from reprocessing waste, Makhijani has documented the threats and questioned the standards used to measure risk. Most importantly, he has stood side by side with local groups who have worked to shut down the offending facilities and ensure that contaminated soil and waterways are cleaned up.

—Excerpt from Ploughshares Fund, Annual Report 2005-2006, on the Web at www.ploughshares.org/annual_reports.php. The eight other Ploughshares heroes were: Edie Allen, Thomas B. Cochran, Gloria Duffy, Gareth Evans, Pervez Hoodbhoy, Rebecca Johnson, Vladimir Orlov, and Amy Smithson.

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